McGRAW-HILL PUBLICATIONS IN THE
ZOÖLOGICAL SCIENCES
A FRANKLIN SHULL, Consulting Editor

PRINCIPLES OF FOREST ENTOMOLOGY

McGRAW-HILL PUBLICATIONS IN THE ZOÖLOGICAL SCIENCES

A. FRANKLIN SHULL, CONSULTING EDITOR

Fernald—
APPLIED ENTOMOLOGY

Graham—
PRINCIPLES OF FOREST ENTOMOLOGY

Haupt—
FUNDAMENTALS OF BIOLOGY

Metcalf and Flint—
DESTRUCTIVE AND USEFUL INSECTS

Mitchell—
GENERAL PHYSIOLOGY

Pearse—
ANIMAL ECOLOGY

Rogers—
COMPARATIVE PHYSIOLOGY

Shull—
HEREDITY

Shull, Larue and Ruthven—
ANIMAL BIOLOGY

Shull, Larue and Ruthven—
LABORATORY DIRECTIONS IN ANIMAL BIOLOGY

Snodgrass—
ANATOMY AND PHYSIOLOGY OF THE HONEYBEE

Van Cleave—
INVERTEBRATE ZOOLOGY

Wieman—
GENERAL ZOÖLOGY

McGRAW-HILL PUBLICATIONS IN THE AGRICULTURAL AND BOTANICAL SCIENCES

EDMUND W. SINNOTT, CONSULTING EDITOR

Adams—
FARM MANAGEMENT

Babcock and Clausen—
GENETICS IN RELATION TO AGRICULTURE

Babcock and Collins—
GENETICS LABORATORY MANUAL

Boyle—
MARKETING OF AGRICULTURAL PRODUCTS

Brown—
COTTON

Carrier—
BEGINNINGS OF AGRICULTURE IN AMERICA

Cruess—
COMMERCIAL FRUIT AND VEGETABLE PRODUCTS

Cruess and Christie—
LABORATORY MANUAL OF FRUIT AND VEGETABLE PRODUCTS

Eames and MacDaniels—
PLANT ANATOMY

Emerson—
SOIL CHARACTERISTICS

Fawcett and Lee—
CITRUS DISEASES

Gardner, Bradford and Hooker—
FRUIT PRODUCTION

Gardner, Bradford and Hooker—
ORCHARDING

Gäumann and Dodge—
COMPARATIVE MORPHOLOGY OF FUNGI

Hayes and Garber—
BREEDING CROP PLANTS

Heald—
PLANT DISEASES

Horlacher—
SHEEP PRODUCTION

Hutcheson and Wolfe—
FIELD CROPS

Jones and Rosa—
TRUCK CROP PLANTS

Loeb—
REGENERATION

Löhnis and Fred—
AGRICULTURAL BACTERIOLOGY

Piper and Morse—
THE SOYBEAN

Rice—
THE BREEDING AND IMPROVEMENT OF FARM ANIMALS

Sharp—
CYTOLOGY

Sinnott—
BOTANY

Sinnott—
LABORATORY MANUAL FOR ELEMENTARY BOTANY

Sinnott and Dunn—
PRINCIPLES OF GENETICS

Swingle—
A TEXTBOOK OF SYSTEMATIC BOTANY

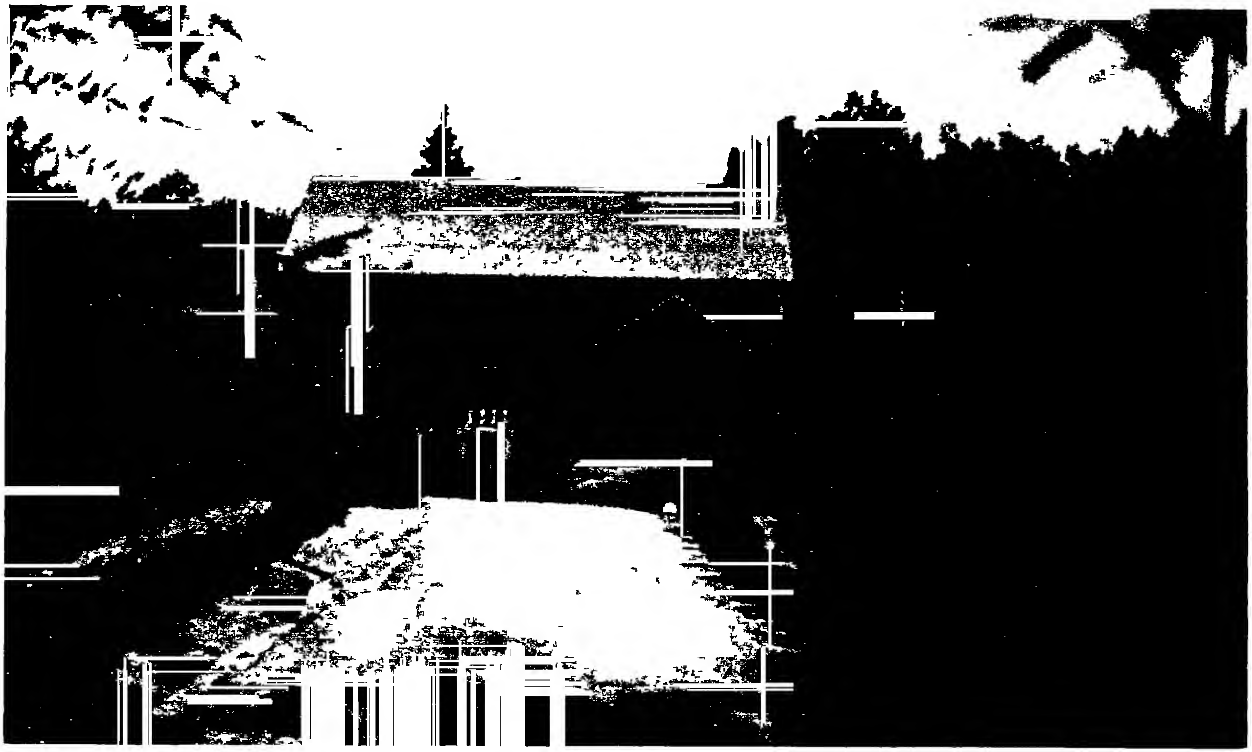
Thatcher—
CHEMISTRY OF PLANT LIFE

Thompson—
VEGETABLE CROPS

Weaver—
ROOT DEVELOPMENT OF FIELD CROPS

Weaver and Bruner—
ROOT DEVELOPMENT OF VEGETABLE CROPS

These two series were originally published as one under the title of McGraw-Hill Agricultural and Biological Publications. The late Dr. C. V. Piper was Consulting Editor from the inception of this series in 1917 until his death in 1926.



(*Frontispiece*)

Forest entomological laboratory of the University of Minnesota at Itasca State Park. This is the field headquarters for cooperative forest insect investigations with the Bureau of Entomology, the Lake States Forest Experiment Station, and the University of Michigan

PRINCIPLES
OF
FOREST ENTOMOLOGY

BY

SAMUEL ALEXANDER GRAHAM
Associate Professor of Forest Entomology, University of Michigan,
Agent, United States Department of Agriculture,
Bureau of Entomology

FIRST EDITION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK 370 SEVENTH AVENUE
LONDON. 6 & 8 BOUVERIE ST E C 4
1929

THE MAPLE PRESS COMPANY, YORK, PA.

TO

ALL INTERESTED IN THE PROTECTION
OF FORESTS AND FOREST PRODUCTS

PREFACE

Teachers of forest entomology have long felt the need of a extbook upon which to base their courses. This book is primarily intended to fill that need, but it is also hoped that its use vill not be limited to the classroom It should be of interest not nly to students and teachers of forest entomology but also to conomic entomologists, ecologists, foresters, and to many others ngaged in growing or utilizing forest products

No detailed consideration of the classification, structure, and netamorphosis of insects is included here, partly because it is elt that in the brief space available these subjects could not be overed adequately and partly because these subjects are horoughly discussed in a number of easily available and excellent vorks which may be referred to for this information.

The author feels that the best approach to the subject of forest ntomology is through a consideration of general underlying rinciples supplemented by a study of certain insect species arefully selected to illustrate how these principles apply in ndividual instances. With this aim in view, a large proportion f this book is devoted to a discussion of these principles, espeially from the ecological viewpoint

Examples of insects illustrating various ecological groups are iscussed in more or less detail These examples have been elected on the basis of their importance as pests In so far as ossible representatives from different parts of North America ave been used. In many instances, other insects might be sed as well as the one selected for illustration References to umerous species that have not been discussed in the text have een included in the bibliography for the convenience of those ho may wish to refer to them.

References to the bibliography are indicated in the text by the ame of the author followed by the year of the publication eferred to. The bibliography has been classified according to hapters and placed at the end of the book so as to simplify its se for general reference No attempt has been made to cite eferences covering any subject completely but, instead, selections

have been made from easily accessible material that will serve as a starting point for a more extensive examination of literature

The illustrations have been drawn from various sources Some of them are photographs taken by the author and many have never been used in previous publications. For permission to use certain illustrations, the author wishes to acknowledge his indebtedness to the Division of Entomology, University of Minnesota, the Bureau of Entomology, U. S Department of Agriculture, and The Entomological Branch, Canada Department of Agriculture. Mr J C Evenden, Mr A. A Granovsky, and Mr Leslie W Orr. Mr William Middleton and Dr T. E. Snyder were especially helpful in aiding in the selection of photographs from the files of the Bureau of Entomology.

During the preparation of this work, valuable advice has been received from many entomologists and foresters Encouragement and suggestions have been received from members of the Division of Entomology and the Department of Animal Biology, University of Minnesota, especially Dr W. A Riley, Dr. R N. Chapman, and Mr A. G. Ruggles. Dr A. G. Boving very kindly examined the historical section; and many others, from time to time, have offered suggestions. The author wishes to express his appreciation to all who have aided either directly or indirectly in connection with the preparation of this book

Finally, the author wishes to acknowledge his obligation to his wife, Sybil Fleming Graham, and to express his appreciation of her valuable assistance in the preparation of this book for publication

SAMUEL ALEXANDER GRAHAM

SCHOOL OF FORESTRY AND CONSERVATION,
UNIVERSITY OF MICHIGAN
December, 1928.

CONTENTS

CHAPTER V

CHAPTER VI

CHAPTER VII

CHAPTER VIII

CHAPTER IX

CHAPTER XV

CHAPTER XVI

CHAPTER XVII

PRINCIPLES OF FOREST ENTOMOLOGY

CHAPTER I

INTRODUCTION

Forest entomology is that branch of the biological sciences vhich deals with insects in their relation to forests and forest roducts. The majority of species treated in this book have a lirect effect either upon the trees themselves or upon the products erived from the trees Some, however, have an indirect effect 1 that they are predaceous or parasitic and prey upon the tree ests In addition to these two types there is a multitude of isects entering into the forest economy that are neither pests of rees nor parasitic or predatory enemies of those pests Examples f these are insects that live upon the plants of the undergrowth, iose that aid in the disintegration of waste wood in the forest, ıd those that feed upon the organic matter in the duff layer of rest soils There can be no doubt that insects of this type play 1 important, if secondary, part in the forest. But they have ceived scant attention from entomologists, and, hence, little known of their activities.

Importance of Forest Entomology in Forestry.—It has been id that forestry is 90 per cent protection One may not accept is high percentage as a fair estimate of the importance of otection, but it must be admitted that if our forests are not to protected from the devastation of forest fire, and the ravages of sects, and of fungous diseases, there will be little opportunity to actice forestry Fire, fungi, and insects are the greatest agents destruction in our forests. Any program of protection which iores any one of this formidable triumvirate endangers our esent and future timber supply and certainly invites disaster. During every stage in the growth of wood, from the seed to the ished product, important insect problems are continually esenting themselves Even before the seeds are collected,

they may be attacked and injured by certain insects that f
upon the seed of either coniferous or deciduous trees. Th
are, for the most part, members of the families Ipidæ (Scolytic
Curculionidæ, or Chalcididæ (Fig 1). Deterioration of the se
due to the activities of these insects, may continue during stor.
In the nursery, the seedlings or transplants may be injured
such defoliators as climbing cutworms, or by root-eating ins
like white grubs and wireworms Bark beetles, leaf or

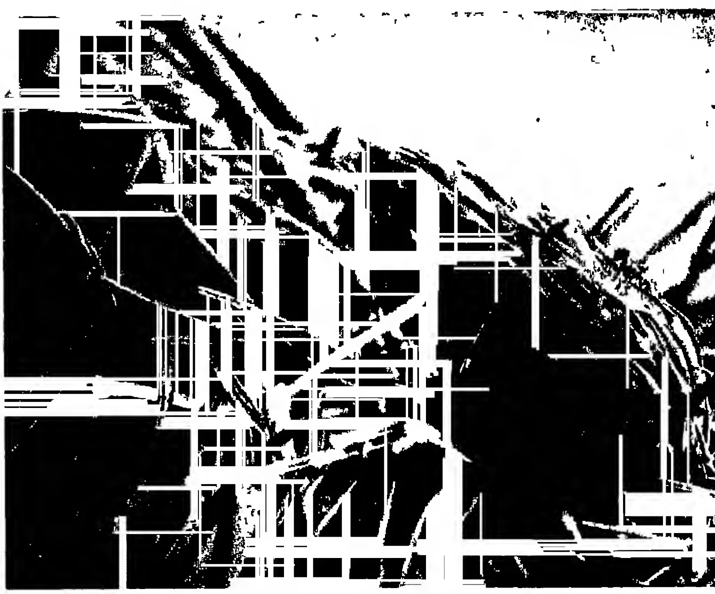


FIG 1 —*Megastigmus spermatophilus*, one of the seed-eating chalcids, ovipo in a douglas-fir cone (*Bureau of Entomology, U S Dept of Agr*)

miners, plant lice, and scale insects all take their toll from
trees in the forest nursery and also from the advance grow
young trees growing under more natural conditions in the fc

Trees in the sapling stage are sometimes attacked and sev
injured by defoliators, cambium insects (Fig 2), and suc
insects The vigorous period between the sapling stage
commercial maturity is, as a rule, the stage most resis
to insect attack Occasionally, even in this period, the trees
succumb to the attack of defoliators or primary bark bee
With approaching maturity the vitality of the trees appea
be reduced, and they become increasingly susceptible to i

injury. Bark beetles that cannot kill vigorous young trees may breed successfully in the trees of the mature forest, and defoliators become much more dangerous than they were when the trees were in the full vigor of youth

Later, when the trees die or are cut, they promptly become subject to the attack of the many kinds of wood-deteriorating insects Bark beetles, ambrosia beetles, round-headed borers (Fig 3), and flat-headed borers all attack and injure dying or recently killed trees and freshly cut wood Not only do these insects injure the wood directly by their borings, but they are often responsible for the introduction of wood-staining and wood-rotting organisms. As the wood seasons or decays, it becomes subject to the attack of numerous other insects

FIG 2 —A white-pine sapling injured by the white-pine weevil The top of the main stem has been killed This kind of injury frequently produces a crooked tree.

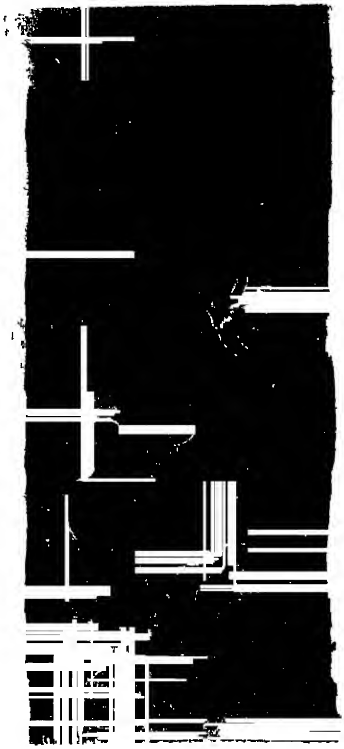


FIG 3.—*Monochamus obtusus* adults on a yellow-pine log from which they have emerged Note the circular emergence holes characteristic of this and other round-headed borers These insects are injurious to freshly cut or recently killed timber (*Bureau of Entomology, U S Dept of Agr*)

With such a multiplicity of insect species attacking trees and wood products, it is difficult, indeed, for a forester to find any line of forestry work in which he is not faced by some insect problem. Even the lumber salesman may be called upon to pacify a customer who finds powder-post beetles (Fig 4) emerging from a newly laid hardwood floor Also, in lumber manufactur-

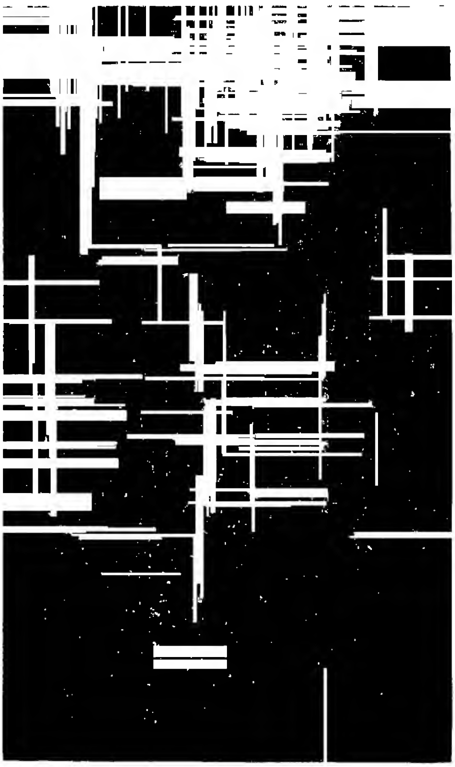


FIG 4—The work of powder-post beetles in finished lumber (*University of Minnesota*)

ing, in the pulp and paper industry, in forest by-product industries, and in the more technical phases of forestry work, entomological problems are forever intruding

In the past, in spite of the tremendous losses caused by insects of forests and forest products, entomology has often been looked upon in forestry as something to be ignored whenever possible. This was due in part, at least, to the feeling among foresters and lumbermen that insects in the forest could not be controlled, and

therefore, should be disregarded whenever possible. But this point of view is rapidly changing, and forest entomology is now properly considered to be an integral and important part of forest protection Forest entomological problems have become so important that they can no longer be disregarded. They must be faced squarely and solved together with our problems in silviculture, management, and utilization.

It is important, therefore, that every forester should be able to recognize evidences of possibly dangerous insect activities and should know enough about insect pests and their control to approach problems intelligently. He should know how and where to obtain information about insects and should be able to apply the necessary remedies intelligently A person totally ignorant of insects and their ways cannot hope to get the best results, any more than a poorly trained physician can hope to give as good service as one who is well acquainted with the disease he is called upon to cure

Losses Due to Forest Insects.—It is undoubtedly true that in North America more wood has been destroyed by insects, fungi, and fire than has ever been cut and used Of these various wood destroyers, insects are by no means the least important

Accurate estimates of losses due to forest insects are very difficult to obtain Certain epidemics, however, have been of such a character that the approximate losses can be estimated with a fair degree of accuracy, but aside from these outstanding instances most estimates are, under present conditions, little more than guesses

A few of the losses resulting from forest insect outbreaks that can be estimated with reasonable accuracy are as follows:

1. Bark beetles in western pine and spruce annually 5,000,000,000 board feet

2. Spruce budworm in Quebec, 1910 to 1920, 200,000,000 cords of balsam fir

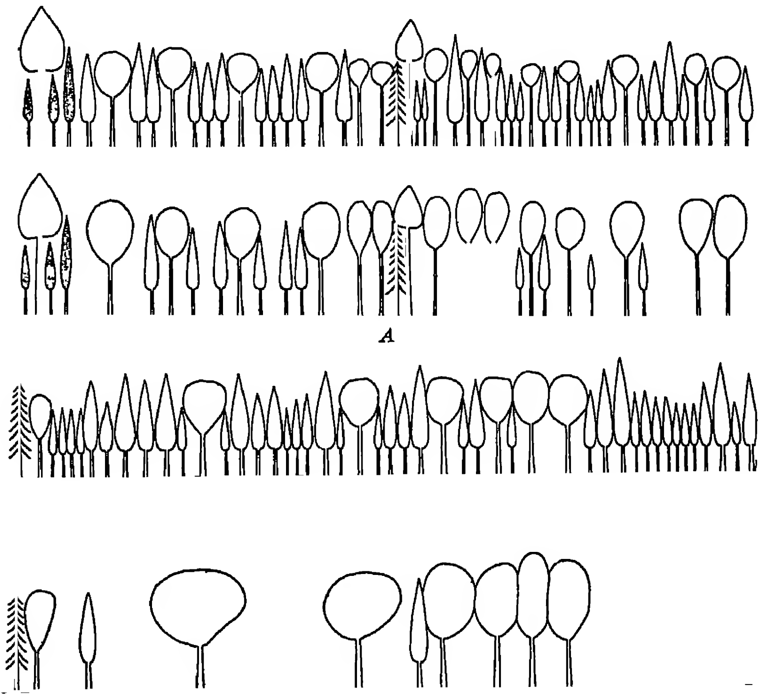
Spruce budworm in Minnesota 1913 to 1923, 10,000,000 cords of balsam fir

Spruce budworm in New England 1910 to 1920, 15,000,000 cords of balsam fir

Spruce budworm total 1910 to 1925, 225,000,000 cords of balsam fir.[1]

[1] This does not include several comparatively recent outbreaks in Canada and the United States concerning which no data are available

3. Larch sawfly in Minnesota 1910 to 1926, 1,000,000,000 board feet of tamarack [1] On the basis of the lowest current stumpage values the average loss to the State of Minnesota alone during the 20 years from 1905 to 1925 as a result of spruce bud-



A

B

FIG 5 —Diagramatic cross-sections of two forest areas, illustrating the effect of a spruce-budworm outbreak upon forests of different compositions Balsam fir is represented by a narrow, unshaded cone, pine by a broad cone, other conifers by a shaded cone, spruce by the figure with drooping branches, and hardwoods by an oval The upper line of trees represents the original condition before the outbreak, the lower, the condition after the outbreak. The relative size of the trees is indicated by the height of the figures *A* represents a mixed stand composed mostly of balsam fir and hardwoods *B* represents a stand where balsam fir was originally the predominating species Note that the injury to the forest is much more severe where balsam fir is most abundant

worm and larch sawfly outbreaks amounts to at least $15,000,000 annually (Fig 5).

Even these data, based as they are upon field observations, cannot be looked upon as being very exact They are, of neces-

[1] In the entire range of eastern larch at least twenty times the above figure was destroyed in the same period

sity, based on a comparatively small number of accurate measurements and a great deal of general observation, with the result that the probable error is high It must also be kept in mind that a considerable portion of the timber killed by both the spruce budworm and the larch sawfly was located in areas that were, and still are, inaccessible for logging In many instances, it is probable that by the time some of these forests will be needed to supply our demands for this kind of timber a new crop of mer-

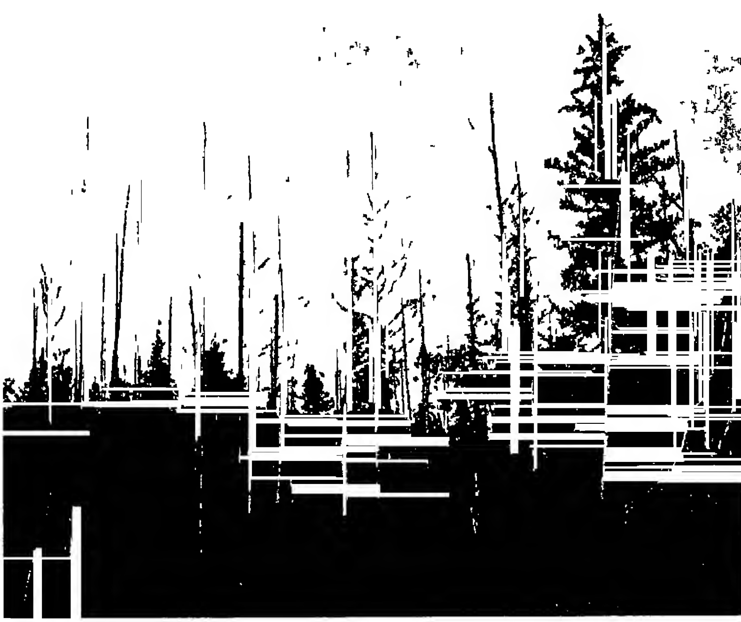


FIG 6.—A tamarack forest killed by the larch sawfly Spruce and young tamarack are replacing the trees killed

chantable trees will have replaced those killed (Fig 6). Thus, although the destruction of timber has been almost beyond human conception, the actual economic loss is somewhat less than it might at first appear to be The destruction of this timber, therefore, was not nearly so serious a matter as will be similar outbreaks in the future

The losses resulting from such outbreaks of insects as those cited above only represent a part of the total damage for which forest insects are responsible. To these losses must be added the less conspicuous but none the less real damage caused by

insects when in normal numbers. The amount of this loss has been estimated in various ways. One of these is to assume a loss of 10 per cent of the total annual cut. On this basis the loss in the United States for the year 1919 amounted to $242,000,000. Whether or not such an estimate is justified by the facts is obviously open to question

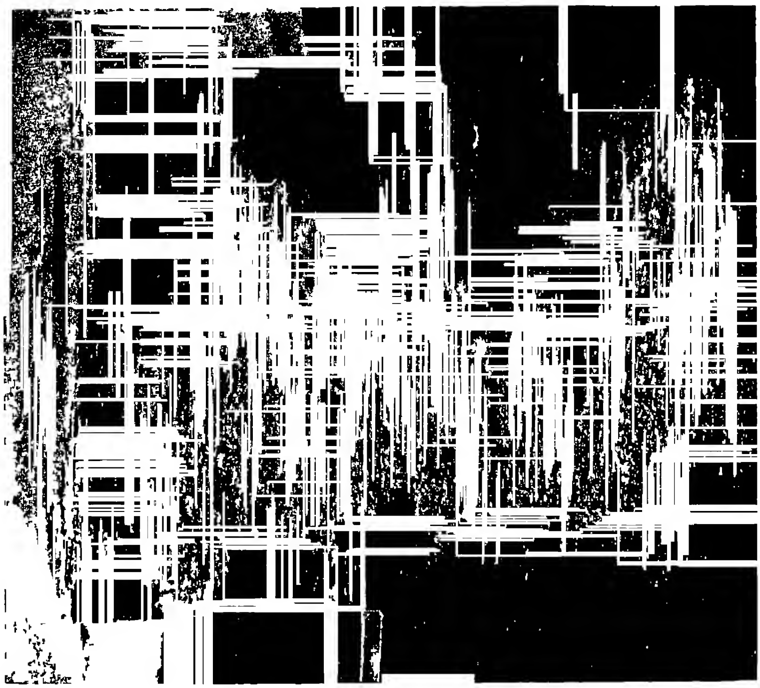


FIG 7—Timbers in the White House, Washington, D C damaged by wood-boring insects (*Hexarthrum ulkei*). This injury necessitated the replacement of the timbers at considerable expense (*Bureau of Entomology, U S. Dept Agr*)

The destruction of manufactured wood-products by insects certainly amounts to a very high total, but no definite data are available at present on which to base an estimate Termites, especially in tropical and subtropical regions, are particularly injurious to unprotected wooden structures. Even in the temperate regions of this country, particularly along the Atlantic and Pacific coasts, termites are sufficiently numerous and injurious to justify special building regulations to avoid injury to wooden structures by these insects Other insects, such as the

powder-post beetles and the pole borer, attack and destroy seasoned wood and finished products, but the data available are insufficient to form the bases for satisfactory damage estimates (Figs 7 and 8).

Incomplete and unsatisfactory as our statistics may be, they are, at least, sufficient to indicate that insects are an important economic factor in our forest industry and should receive an important place in our plans for the protection of our forests and forest products

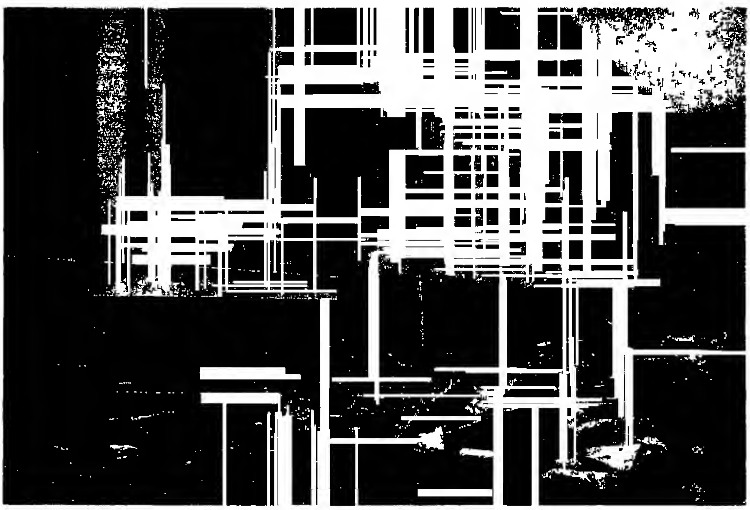


FIG 8—One of the Internal Revenue buildings in Washington, D C, injured by termites to such an extent as to necessitate the replacement of the supporting timbers. (*Bureau of Entomology, U. S. Dept Agr.*)

Scope and Subdivisions of Forest Entomology.—The scope of forest entomology is wider than may at first appear to be the case. It includes a great variety of materials leading to the better understanding of the biological phenomena of forest life The ultimate aim of forest entomology is to make possible the regulation, in the interest of man, of insect activities in forest and forest products. In the control of forest insects, directly protective methods can seldom be applied, because of the excessive cost of such operations. As a rule, one is compelled to resort to preventive rather than to curative methods. This preventive entomology calls for a much more profound knowledge of both the insects and the forest environment than if one could depend

largely upon direct control One of the first requisites for forest insect work, therefore, is a sound basic knowledge of silvics and silviculture Not until one knows his trees is he in a position to apply his entomological knowledge to them.

On the other hand, one must know his insects. To know an insect one must not only be able to recognize the genus and species to which it belongs, but he must also understand its functions, its reactions to its environment, and its physical limitations. Thus, all of the major divisions of the science of entomology are needed in the solution of forest entomological problems. The taxonomist is needed to classify insects and to study their relationships and origin. He not only aids the forester by giving him names, but also when a new forest entomological problem presents itself he may actually furnish the key to satisfactory control measures For closely related insects can often be controlled by similar means, and the service of the taxonomist in showing relationships of new to old pests may often prove invaluable. Studies in morphology, histology, and physiology of forest insects lead to a more complete knowledge of the insects studied and aid directly or indirectly in the solution of forest entomological problems Chemical entomology, which includes spraying, dusting, and fumigating for the control of insect pests, has its place in the control of certain tree insects Ecological studies, including life history investigations, the effect of climatic and other environmental factors upon forest insects, and the interrelation of parasites and predatory species with their hosts, are all of fundamental importance in forest entomology.

Obviously, no forest entomologist can be expected to have the detailed knowledge of taxonomy that is expected of a specialist in taxonomy and at the same time be a specialist in morphology, histology, physiology, ecology, and chemical entomology. The field is too large to permit of such a wide scope of endeavor. On the other hand, he is expected to have a general knowledge of each of these fields and to have a detailed knowledge of some of them. At the present time, forest entomologists in the United States and Canada are centering their attention for the most part upon either taxonomy, or ecology, or both; in Europe, however, at least some of the workers in forest entomology are attacking problems of a morphological, histological, or physiological nature It is probable that the future may see the develop-

ment of specialists within the field of forest entomology just as we now have specialists in other fields of entomology. If such specialization does come to pass, let us hope that the workers will avoid the danger of overspecialization and will continue to maintain their grasp of the general field, and thus keep a proper perspective of forest entomology as a whole

Forest Entomological Literature.—Every student must rely on the writings of others for a foundation of information in any given line The ability to locate all available literature on any subject and to use that literature efficiently is essential for best results The library is one of the most important tools In the field of forest entomology there is particular need for training in the ways and means of locating information, because the writings in this field are so scattered that they are sometimes difficult to find and may easily be overlooked

Fortunately for the student of forest insects, American economic entomology is unusually well provided with a series of indexed bibliographies published by the United States Department of Agriculture and by a series of indexes published by the American Association of Economic Entomologists Volumes one to five, inclusive, of the indexed bibliography entitled, "Bibliography of the More Important Contributions to American Economic Entomology," were compiled by Samuel Henshaw The first three volumes were devoted to the writings of B D Walsh and C. V Riley, two men who were perhaps the most prolific writers that entomology has ever known. Volumes four and five cover the writings of other authors up to 1888. Volumes six to eight, inclusive, of this series were compiled by Nathan Banks and cover the period from 1888 to 1905. The series was then discontinued by the Department of Agriculture. The work was later taken up by the American Association of Economic Entomologists, and the index portion continued The first volume of this index was compiled by Banks and covers the years 1905 to 1914, inclusive. Since then two more volumes have appeared, both compiled by Mabel Colcord The first of these covers the period from 1915 to 1919, inclusive, and the second 1920 to 1924, inclusive.

These bibliographies and indexes provide a ready means of access to most of the important economic entomological literature of the United States and Canada, but they do not help where other literature is concerned For this one must go to other

works, the most important of which is probably the *Zoological Record* This record has been published annually since 1864 by the Zoological Society of London, and aims to include all publications dealing with animals A large part of each volume is devoted to entomological literature Periodical index numbers are published For information previous to 1864 one may go to the "Index Literaturae Entomologicae," compiled by Hagen, Horn, and Schenkling

Due to the fact that much forest entomological information has been published in forestry journals, trade journals, and other publications, not ordinarily examined in the compilation of the bibliographical aids just mentioned, the forest entomologist must not neglect forestry literature or he may miss important contributions This is particularly true of European literature. No indexes in English of forestry literature comparable to those of entomological literature have ever been published. This lack adds to the difficulty of bibliographical work. *The Journal of Forestry* and its predecessor, the *Forestry Quarterly*, have published monthly lists of literature since 1902, and thus is provided a readily accessible reference to many forest entomological articles not included in entomological bibliographies and indexes

The indexes and records mentioned above aid the student in his search into the past, but this is only a part of his problem Often several years may pass between the date of publication of an article, and the publication of an index referring thereto. This gap must be bridged, which is no light task when one considers the scores of periodicals, bulletins, circulars, and books coming from the press each month that may contain forest entomological information Even though each worker had access to every article in the mass of literature, he could scarcely be expected to take the time to examine all of them. As a time saver and an aid in keeping in touch with recent progress, the reviewing and abstracting periodicals are a great aid. These publications are usually only a few months behind the publication of original papers.

One of the most important reviewing organs for the entomologist is the *Review of Applied Entomology*, published in London by the Imperial Bureau of Entomology. This publication appears monthly and aims to review every article published in the field of economic entomology. It is world wide in its scope and misses very few publications of importance. In the United States, the *Experiment Station Record*, published by the Department of

Agriculture, covers a large part of the American literature *Botanical Abstracts*, *Physiological Abstracts*, and *Chemical Abstracts* often contain abstracts of articles that may be of value to the forest entomologist.

Biological Abstracts, a new publication starting with January, 1926, is expected to supersede most of the older abstracting agencies, because it covers the entire field of biology By bringing together world-wide biological literature in this way the problem of the individual worker in keeping abreast of the times will be greatly simplified.

Convenient and useful as they may be in helping workers in the various fields to keep abreast with scientific progress, there lies a danger in the use of these abstracting periodicals: the danger that one may neglect reading original articles. It must be remembered that an abstract does not take the place of the original but only serves to indicate whether or not the original is of sufficient importance to be read The student of entomology must be familiar with all the original sources that apply to the work at hand.

Some of the sources in which one ordinarily expects to find American and Canadian forest entomological work published may be listed as follows:

1 UNITED STATES DEPARTMENT OF AGRICULTURE
   Department bulletins and circulars
   Bureau of Entomology bulletins and circulars
   Farmers' bulletins
   Year books and reports.
2 STATE PUBLICATIONS:
   Experiment station bulletins, circulars, and reports.
   University bulletins and memoirs
   State entomologist publications
3 BULLETINS AND CIRCULARS OF THE ENTOMOLOGICAL BRANCH, CANADA
4. PERIODICALS
   Journal of Economic Entomology
   Journal of Agricultural Research
   Journal of Forestry (*Forestry Quarterly* and *Proceedings of the Society of American Foresters*)
   Canadian Entomologist
   Canadian Lumberman
   American Lumberman
   Proceedings of the Washington Entomological Society
   Proceedings of the Entomological Society of Ontario
   Proceedings of the Entomological Society of Nova Scotia
   Proceedings of the Entomological Society of British Columbia

In England, a considerable proportion of the forest entom logical work is conducted by the Forestry Commission ar appears in its publications Other articles appear from tin to time in the *Journal of Ecology* and other periodicals St other articles on entomology are published in the *Indian Foreste* and official publications of the Indian Government, and al in the official publications of the respective governments Australia and South Africa In addition to publications printe in English, there are many periodicals in foreign language particularly German Of these one of the most outstanding the present time is the *Zeitschrift für angewandte Entomolog* edited by Escherich. Almost all of the European forestry an entomological publications print occasional papers on fore insects.

Although the major portion of European forest entomologic literature appears in the form of pamphlets and short article there are a number of important books on the subject I America, however, forest entomological books are very fev In fact, there is no general comprehensive work comparabl with some of those that may be cited from European countrie About the only American books that deal with forest insects ar

Packard, 1890, "Insects Injurious to Forest and Shade Trees" Fift Report of the Entomological Commission, U S Dept Agr

Felt, 1905, "Insects Affecting Park and Woodland Trees" *Mem* 8, Ne York State Museum.

Felt, 1924, "Manual of Tree and Shrub Insects"

One of the best manuals of general entomology is:

Comstock, 1925, "An Introduction to Entomology"

Some of the outstanding English and European texts are:

Gillanders, 1908, "Forest Entomology"

Escherich, 1914 to 1923, "Die Forstinsekten Mitteleuropas" (A revision Judeich and Nitsche's "Lehrbuch der Mitteleuropaischen Forstinsekter kunde").

Trägårdh, 1914, "Sveriges Skogs Insekter"

Cecconi, 1922, "Manuale di Entomologia Forestale"

Nüsslin-Rhumbler, 1922, "Forstinsektenkunde"

Barbey, 1925, "Traité D'Entomologie Forestière"

Because forest entomological literature is so widely scattere in so many different publications, it is obvious that no loca library can have on its shelves copies of all the entomologica publications that one may wish to examine Even in some c

our best entomological libraries, it is often impossible to find every article which may be of interest Fortunately, however, most of the local libraries have the privilege of borrowing from other libraries, or if the publications themselves cannot be borrowed, photostat copies of parts of articles or books can usually be obtained; consequently, if one has a definite reference, it is usually possible to see a certain publication even though the facilities of the local library are rather limited. The first and most important thing that one needs when one begins to look up the literature on any subject is to have at his command adequate bibliographical aids in the form of indexes and abstracting organs, such as have been mentioned above. With these at one's command, one can search through literature effectively, without them, one is helpless One should see, therefore, that the local libraries are equipped with at least these very necessary tools

CHAPTER II

HISTORICAL REVIEW

The science of forest entomology, like the science of forestry of which it is a part, is very young It had its beginning during the first part of the nineteenth century

DEVELOPMENT IN EUROPE

In as much as Germany was the first country to develop forestry, it is natural that in that country forest entomology should have had its inception. As the value of trees became more and more appreciated and methods of silvicultural practice were developed, the necessity of protecting the trees from the ravages of insects became increasingly important.

The Pre-Ratzeburg Period.—The outbreak of a forest pest was something with which the early foresters were unable to cope, and so they were forced to call on others for help They appealed to the zoologists. As a result of these early appeals, a number of publications appeared that dealt with various individual forest insect problems. For instance, one finds such treatises as that of Gmelin, "Abhandlung uber die Wurmtrocknis," published in 1773, and that of Hennert, "Uber die Raupenfrass und Windbruch," published in 1798

The purpose behind most of these early studies of forest insects was the development of methods by which a certain pest or the pests of a certain tree might be controlled It is true that this end was seldom accomplished, and that the chief contribution of these studies to science was either taxonomic or biologic in character. Sometimes, however, effective measures were suggested and applied For instance, Linnaeus is said to have recommended that freshly cut logs be floated in water to prevent injury by borers—a very effective method that is in use today

Previous to 1800, forest entomology, as such, did not exist There were no specialists in this subject, and the studies of tree insects were conducted by men whose primary interest was in

other lines of work. The first attempt to gather together all available information concerning forest insects was that of Beckstein and Scharfenberg who published, in 1804 and 1805, two volumes entitled, "Vollständige Naturgeschichte der fur den Wald schadlichen und nutzlichen Forstinsekten." This was a very pretentious compendium of forest insect information, and for a period of 30 years was the only general work available on the subject

The Period of Ratzeburg.—Then there appeared a monumental work which even today has never been surpassed in excellence

FIG 9—Dr Karl Escherich of the University of München, Germany He is an outstanding figure in forest entomology and has contributed greatly to the advancement of this subject especially in Germany (*R N Chapman*)

and scope This was Ratzeburg's "Die Forstinsekten" Ratzeburg was the first man to devote all his energies to forest entomology and he has frequently been called the father of forest entomology. He lived in an age when specialization was the exception rather than the rule. Even he attempted at first to cover forest pathology as well as forest entomology, but he soon found that these two subjects were too extensive to be handled effectively by any one man. His later work, therefore, was confined to the field of entomology

The first volume of "Die Forstinsekten" appeared in 1837, the second in 1840, and the third in 1844 He also published a handbook, "Die Walverderber und ihr Feinde," that summarized

in more condensed form the material contained in "Die Forstin sekten" The demand for this handbook was so great that b 1869 it appeared in its sixth edition. After Ratzeburg's deatl in 1871, this book continued to appear in new editions edite by his successors Judeich and Nitsche published a book whic purported to be a revision of this work of Ratzeburg's (188 in two volumes under the title "Lehrbuch der mitteleuropaische Forstinsektenkunde." Still more recently, Escherich has pub lished a new edition, which is a masterpiece of its kind, under th title "Die Forstinsekten Mitteleuropas" Escherich (Fig. 9) ha added much new material and has rewritten the older portion c the book, thus making a thoroughly modern presentation of th subject. Ratzeburg continued to publish during his long an productive life. One of his best-known works is his "Ichneu moniden der Forstinsekten," published in three parts in 184 1848, and 1852 Ratzeburg dominated the period during whic he lived. But although he stood head and shoulders above h contemporaries, there were other workers who made very valu able contributions to the science of forest entomology Amon them we find Kollar, Hartig, and Nordlinger in Germany, an Perris in France. The most important contribution of Koll is a "Treatise on Insects Injurious to Gardens, Forests an Farms" It has been translated from the German. Perris credited with the first experimental studies in forest entomolog He cut trees at different seasons and studied the life history an habits of the various insects that attacked them His greate contribution was the "Histoire des Insectes du Pin Maritime, which appeared in ten parts between 1851 and 1870 in the Anna of the Entomological Society of France.

The Period of Eichhoff.—Up to the time of Ratzeburg death, the chief emphasis in forest entomology was placed on th biological studies. These investigations were often in the natu of general natural history studies and were usually not base upon controlled experimental evidence The work of Eichho ushered in a new era which made of forest entomology a mo exact science than it had previously been. By combining caref biological experiments and detailed systematic studies, he cleare up many misconceived notions concerning the biology of ba beetles and set up a model for other investigators to follow H outstanding contribution, entitled "Europaischen Borkenkafer was published in 1881.

During the later part of the nineteenth century there were, particularly in Germany, many workers who devoted a part or

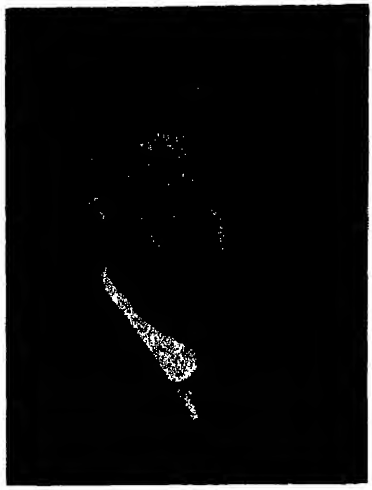


FIG 10—Dr J. W Munro, one of England's foremost forest entomologists (*R N Chapman*)

FIG 11—Dr J M Swaine, Chief of the Division of Forest Insects, Entomological branch of Canada. (*Bureau of Entomogy, U S. Dept Agr*)

all of their time to the study of forest insects Among them was Altum, at Eberswalde who did much by his work to stimulate investigation and discussion as a result of the theories and hypo-

theses which he proposed. Nitsche, at the Forstakademie in Tharand (Fig. 11), and Henschel, at the Agricultural High School at Wien, were both outstanding teachers and investigators

The Modern Period in Europe.—From the very beginning until the end of the nineteenth century European forest entomologists looked to Germany for leadership This was the natural result of the tremendous amount of valuable pioneering work on forest insects produced by the entomologists of that country Since the beginning of the twentieth century a decided change has been taking place until now in the modern period

Fig 12.—Dr Ivar Trägårdh, foremost forest entomologist of Sweden.

leaders in forest entomology, instead of being centered in a single country, are to be found throughout those parts of the old world where forests are economically important Germany still has her great men in forest entomology who are contributing much to the science; Escherich, Rhumbler, and Prell are some of these But they no longer stand alone Tragårdh (Fig 12) in Sweden Saalas in Finland, and Munro (Fig. 10) in England, all must be regarded as leaders in their field

In Europe, the science of forest entomology has, in general passed through several more or less definite periods The first was the natural history period that was characterized and dominated by the work of Ratzeburg The second was the period of great taxonomic activity supplemented by experimenta

life-history studies Eichhoff characterizes this stage which was really the connecting link between the first period and the third. In the third, or modern, period the great emphasis is placed on experimental biology One of the outstanding figures in the early part of this period was Nusslin He has been followed by a host of other workers, among them Hennings who was the first to study bark beetles under controlled temperature and humidity Unfortunately for forest entomology, his work was cut short by his untimely death

DEVELOPMENT IN AMERICA

During Ratzeburg's period of domination in Europe, an interest in tree insects was developing in America.

The Natural History Period in America.—The earlier contributions in America, like those in Europe, dealt largely with forest insect biology from the natural history viewpoint. These early writings are both useful and interesting to us today, but unfortunately they are so scattered in various publications that they are sometimes difficult to obtain. Fortunately, most of this material is referred to in the indexes already discussed Many articles on tree insects are included in Harris' "Treatise on Some of the Insects Injurious to Vegetation" (1886) and in Fitch's Reports on "Noxious, Beneficial and Other Insects of the State of New York" (1856 to 1870) The reports and articles of Walsh, Riley, Lintner, Comstock, and Forbes also contain much information concerning forest insects.

But it was not until 1890 that the first compendium on American forest insects was published At that time Packard brought together all the available material in the fifth report of the Entomological Commission of the U S Department of Agriculture entitled, "Insects Injurious to Forest and Shade Trees" This report contains a mass of valuable information concerning tree insects and is well illustrated by numerous plates and figures Packard included verbatim many of the important articles by other authors which are not, as a rule, easily accessible and this adds materially to the value of his book for reference. For years, Packard's report was the only comprehensive work on American forest insects Then, in 1905, was published *Memoir* 8 of the New York State Museum, by Felt, entitled "Insects Affecting Park and Woodland Trees" This added some new

information to that included in Packard's report, but its ch
value was in its remarkably fine colored illustrations

The Taxonomic-biological Period.—Then followed a peri
when taxonomic-biological studies predominated in forest ent
mological work This period was similar in character to t
Eichhoff period in Europe, the influence of which was evide
upon American work of the early part of the present centu

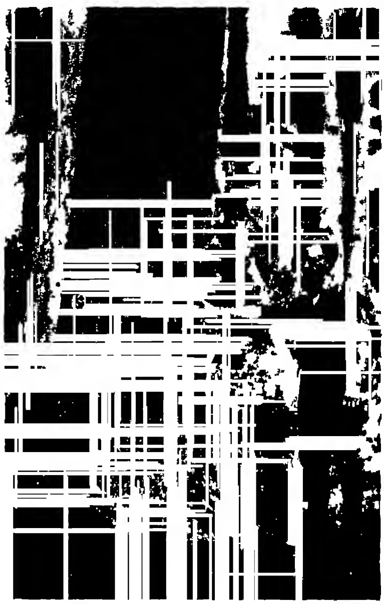


FIG 13—F C. Craighead, Chief of the Division of Forest Insects, Bureau
Entomology, U S Department of Agriculture, studying a western yellow p
that is infested with dendroctonus beetles (*J C Evenden*)

Hopkins in his bark-beetle studies has added much to
knowledge of that group of insects both biologically and ta
nomically He was able by his work, like Eichhoff, to dis
many incorrect views that had previously been held concern
both the bark beetles and the bark weevils

Most of the work of both Swaine (Fig. 11) and Blackn
belongs in the taxonomic-biological category, and some of
earlier work of Craighead was along similar lines, but at pres
all three of these men are working along the lines of exp
mental biology (Fig 13)

During the early periods in America the emphasis was placed on shade-tree insects. Virgin forests were still supplying an abundance of wood products, and the practice of forestry was practically unknown, because it was unnecessary. The few methods of forest-insect control that were mentioned in the publications of that time were for the most part borrowed from continental Europe. This situation has continued until very recently. Even today tree insects are receiving much more attention as shade-tree pests than they are as enemies of the forest. A rapid change in point of emphasis is now taking place.

The Modern Period in America.—In Europe, the emphasis, since the earliest development of the science, has been placed on insects of the forest. This has been the result of economic conditions, characteristic of densely populated communities, where a scarcity of wood has made the practice of forestry a necessity. The forest entomological investigations, moreover, have been centered in the forest schools as an integral part of the forestry work. In America, on the other hand, the work on tree insects has, until recently, been conducted in a large measure by entomologists whose interests and training were in no way connected with forests or forestry. As a result, the insects have been studied primarily for their own sake and their relationship to the forest has consequently often been of subsidiary importance.

The modern viewpoint of forest entomology is quite different, however. As forestry has developed in America there has been an ever-increasing need for information concerning the influence of forest insects upon the forest. Where in the past there were almost no men spending their entire time upon forest insect problems, there are now many capable men employed in this work. These men are interested both in the insects themselves and in the forest, but their primary interest is in the influence of insects upon the forest.

This point of view has resulted during recent years in the application of experimental biological methods to forest entomological problems. The natural history method of study has been largely abandoned, and taxonomy is no longer thought to be an end in itself but merely one of the useful tools of the profession. Life-history studies are likewise regarded as means to an end rather than ends in themselves. The interrelations of insects with one another and with the various other elements

of the forest environment are coming to be regarded as more and more important

Thus the development of forest entomology in America has passed through stages that are more or less comparable to the development of this branch of science in Europe. The first or natural history period was contemporaneous with a similar period in Europe So also was the taxonomic-biological period contemporaneous with similar efforts in the Old World The application of the methods of experimental biology, likewise, appeared in Europe and America about the same time These methods have led to the recent rapid development in the fields of ecology, physiology, genetics, and biometry Forest entomology, like the other biological sciences, is now being built up rapidly on the basis of experimental work

CHAPTER III

BIOTIC POTENTIAL

The actual abundance of forest insects in general and of any one species in particular will depend upon their ability to multiply, and to live, in spite of the various destructive forces in their environment Before it can be ascertained what the actual abundance of any insect will be, one must take into careful consideration, in the first place, the ability of that insect to multiply in the absence of any destructive force and, in the second place, the value of the sum total of all the environmental forces working toward destruction. In other words, life is the result of a struggle between the forces of potential creation and potential destruction Chapman (1925) has proposed apt terms for these two opposing forces, namely *biotic potential* and *environmental resistance*

The factors which enter into the composition of these two forces will be discussed under the above terms in two separate chapters The relationship of the two forces to one another in producing insect abundance will be left to a third chapter

THE RATE OF MULTIPLICATION

The biotic potential of an insect species is its ability to multiply in a given time when relieved of all environmental resistance It depends upon the rate of multiplication and the sex ratio The rate of multiplication, in turn, is determined by an insect's fecundity and the length of the developmental period.

Fecundity.—The ability to produce young is one of the basic factors determining biotic potential Among insects there is a wide range of variation in this ability. The number of eggs that may be deposited by a single female may vary from a very few, as is the case with some wasps, to hundreds of thousands, as with the termites

In general, the fecundity of insects is relatively high. Folsom (1922) quotes Mauw to the effect that two females of the broad-necked root borer, *Prionus laticollis*, were found to have in their

ovaries 332 and 597 eggs, respectively. He further cites Girault as authority for the following data concerning the fecundity of certain species:

	Maximum	Minimum	Average
The evergreen bagworm, *Thyridopterix ephimeræformis*	1,649	465	941
The apple-tree tent-caterpillar, *Malacosoma (Clisiocampa) americana*	466	313	375.5
The scurfy scale, *Chionaspis furfura*	84	33	66.5

Other investigations have shown that the white-pine weevil, *Pissodes strobi*, lays on the average 115 eggs per female (Graham 1926), the spruce budworm, *Archips fumiferana*, 175, the forest tent-caterpillar, *Malacosoma disstria*, about 300 (Fig. 14). Counts made by the author's class in forest entomology showed that the scurfy scale, in the season of 1926, laid an average of 25.6 eggs per female, with a maximum of 52 and a minimum of 6. This is a considerable variation from the figures cited above. The oyster-shell scale, *Lepidosaphes ulmi*, produced on the average 27.4 eggs per female, with a maximum of 68 and a minimum of 2. The white-marked tussock-moth produced on the average 231.8 eggs per female with a maximum of 467 and a minimum of 174. High as these figures are, it is improbable that in any of these cases the maximum possible number of eggs were deposited. For instance, dissection and examination of a series of tussock-moth females showed an average of 476 fully developed eggs per female, with a maximum of 764 and a minimum of 202, much higher figures than those based on counts of the eggs actually deposited.

Some insects possess a device which very materially increases their ability to reproduce young. This is called polyembryony. It occurs commonly among small hymenopterous parasites, notably the Proctotrupidæ. A single egg deposited by an individual of a polyembryonic species produces many individuals (Fig. 15). Such a species, although it may produce comparatively few eggs, may still have a high rate of fecundity.

Length of Developmental Period.—The rate of multiplication is dependent not only upon fecundity but, also, upon the length of time required for the completion of each generation. Many insects develop slowly. Certain species of Cerambycidæ, for

example, *Monochamus confusor*, the large pine sawyer, require under the most favorable conditions a full year to complete a generation There have been records of some borers that lay their eggs only in freshly cut logs emerging as adults from furniture 20 years old. It must be admitted that such extremely long developmental periods are unusual even among wood borers and are the result of unusually adverse conditions A few insects, however, for example, the periodical cicada, have a normal life cycle almost as long as this.

On the other hand, some of the fruit flies of the genus Drosophila, under favorable conditions, may complete their development from egg to adult in less than 1 week, and we may thus have from 10 to 20, or even more, generations per year Thus the short life cycle of such insects, coupled with the high fecundity of the individual insects, makes possible a rate

FIG 14

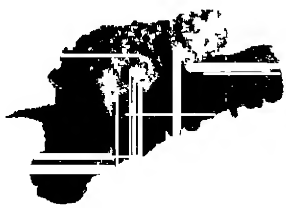


FIG 15

FIG 14 —An egg mass of the forest tent-caterpillar on an aspen twig Note that the ends of the cluster are cut off rather abruptly This characteristic will distinguish the egg mass of the forest tent-caterpillar from other closely related species of tent-caterpillars

FIG 15.—A mass of cocoons of a small hymenopterous parasite, spun upon the body of a dead sphinx larva The 40 or 50 parasites contained in these cocoons originated from only a few eggs This illustrates the results of polyembryony (*University of Minnesota*)

of multiplication too great for the mind to comprehend. As an illustration of these tremendous possibilities the calculation of LeFroy (1909) concerning the unrestricted multiplication of Drosophila may well be cited He calculated that a single pair of fruit flies, if all their progeny lived and in turn reproduced themselves under favorable conditions, would in one year produce a mass of flies that, if packed 1,000 to the cubic inch, would cover the entire area of India to a depth of 100,000,000 miles or

would cover the earth to a depth of 1,000,000 miles Such a potential seems almost beyond belief since, owing to the effects of environmental resistance, the complete realization of such a possibility may never be seen Nevertheless, the immense power of the biotic potential must not be overlooked

SEX RATIO

The next of the important factors determining the biotic potential of a species is the proportion of males and females that is characteristic of the species This proportion is determined, in part at least, by the habits of reproduction

Habits of Reproduction.—Sexual reproduction is the type most commonly found among insects, although either partial or complete parthenogenesis is characteristic of many species This latter habit of reproduction occurs very commonly among the Hymenoptera. That important forest pest the larch sawfly, *Lygeonematus ericsonii*, is partly parthenogenetic So also are plant lice, which give birth parthenogenetically to many generations of agamic females. In this way, many more individuals are produced during a season than would be possible under sexual reproduction

In general, the females predominate in parthenogenetic species. This holds true in the case of the larch sawfly which has 96 females to 4 males With such a high proportion of females the number of progeny resulting from any one generation of this species is much greater than would be the case under the usual proportion of the sexes, that is, approximately one-half males and one-half females. The ratio of females to the total population is known as the *sex ratio* and must be taken into consideration in calculating biotic potential. The sex ratio of a species is determined by dividing the number of females in a given group by the total number of individuals in that group. Thus, if the sexes occur in equal numbers, the sex ratio will be 0 5. In a purely parthenogenetic species, in which no males occur, the sex ratio will be 1 0. In the case of the larch sawfly, mentioned above, the sex ratio is 0.96.

The Effect of Sex Ratio.—The important part that sex ratio plays in determining the biotic potential of a species may be illustrated by a simple calculation comparing two hypothetical insect species, one of which produces equal numbers of males and females, while the other produces a great predominance

of females. We will assume that each of these species lays 100 eggs per female. If we start with two individuals of each species and calculate the rate of multiplication for each through five generations of progeny, assuming that each female lays her full quota of eggs and that every egg produces an adult individual, we shall see a great difference in the final numbers for each species

TABLE I—HYPOTHETICAL YOUNG PRODUCED DURING FIVE GENERATIONS

Generations		First	Second	Third	Fourth	Fifth
Species No 1	Males 1	50	2,500	125,000	6,250,000	312,500,000
	Females 1	50	2,500	125,000	6,250,000	312,500,000
	Totals	100	5,000	250,000	12,500,000	625,000,000
Species No 2	Males 0	0	0	0	0	0
	Females 2	200	20,000	2,000,000	200,000,000	20,000,000,000
	Totals	200	20,000	2,000,000	200,000,000	20,000,000,000

In the fifth generation, it will be seen that species Number 1 in which the males and females are of equal number has reached a total of 625,000,000 individuals, while species Number 2 composed solely of females has a total of 20,000,000,000 Thus, it is evident that sex ratio is of vast importance in determining biotic potential because it expresses the numbers of individuals in each generation of a species that are capable of producing new individuals

THE CALCULATION OF BIOTIC POTENTIAL

Unless a specific numerical value for the biotic potential of a species can be assigned, the term can have little or no practical significance. Until now it has been impossible to arrive at such a value because the knowledge of the factors concerned has not been sufficient

In order to calculate the value of the biotic potential of a species, all of the factors that have just been discussed must be taken into consideration. The number of ovules that a single typical female is capable of producing, the number of generations that will be produced in a given time under optimum conditions, and the sex ratio all must be known The values

for these factors are, so far as known, practically constant for any species of insect existing under ideal conditions, and they are sometimes called the constants for that species If these constants are known, then the biotic potential of any species may be calculated

Values for Fecundity.—Since, according to the definition, these constants represent values for factors when the insect species is under ideal conditions, any statistics obtained from insects living under ordinary natural conditions, which are usually not ideal, cannot be taken In the case of fecundity, for instance, it is not the number of eggs which a typical female of a species actually lays that is the constant for that species but the number she is capable of laying To secure this potential number several methods may be used The most accurate would be to rear a number of females from eggs to adults under ideal conditions and count the total egg production of each This method is both difficult and time consuming; therefore some easier way is desirable.

One method that is easier but, unfortunately, not so accurate is to count the fully developed eggs in the ovaries of gravid females that have never laid eggs and assume the maximum number found in any one female to be the constant for that species. This method gives an approximate value for fecundity which may be used tentatively for those insects that lay their full quota of eggs within a few days It cannot be used as an index of fecundity in species having a long period of oviposition, because such species continue to mature eggs throughout their lives

A similar, but more difficult, method has been suggested that may prove to be more accurate This consists of counting the number of primary oocytes in the ovaries of recently matured females. It is thought that the number of primary oocytes may be the same for all the individuals of a species If this be true and if it could be assumed that from every oocyte an egg would be produced, then a method would be found which would be less difficult than the counting of eggs from females reared under optimum conditions through all stages from egg to adult, and one that would be more accurate than the counting of eggs in gravid females living under natural conditions Until these assumptions are proved correct, it will be necessary in determining a constant for fecundity to use the most accurate values

obtainable either from rearing studies or from egg counts in gravid females

Values for Other Factors.—The values for the other factors that enter into the calculation of biotic potential are more easily obtained. For instance, the determination of the sex ratio may be accomplished by rearing a large number of individuals and determining the number of each sex in the group. The number of generations in a given period and the number of individuals produced from a single egg may also be determined by simple rearing experiments. Chapman, in the calculation of biotic potential has used with adaptations a mathematical formula, proposed by Thompson (1922) to express the number of progeny that will result from a given population in any number of generations In this formula p represents the original population, which in the calculation of biotic potential will be a single pair, z represents the product of the number of eggs per female and the sex ratio, and n represents the number of generations in a given time Then the number of progeny in n generations is $(pz)^n$ This formula is sound except when dealing with species which are polyembryonic, in which case it is necessary to include that factor also For instance if y represents the number of progeny arising from a single egg the formula will then read $(pzy)^n$

For example, if it is assumed that the egg-laying capacity of the white-marked tussock-moth is 764 eggs per female (the maximum number of fully developed eggs recorded as found in gravid females), the sex ratio is 0 5, the number of individuals produced from an egg is 1, and the number of generations per year is 1, then the annual biotic potential for the species, starting with a single pair is $(2 \times 382 \times 1)^1 = 764$ If, however, this were a polyembryonic species producing 4 individuals from a single egg, and if it passed through two generations per seasons the biotic potential would be $(2 \times 382 \times 4)^2 = 9{,}339{,}136$

This simple calculation demonstrates clearly the importance of each of the various factors of biotic potential. Fortunately for man, this stupendous potential of creation is held in check by the forces of destruction that will be analysed in the following chapter

CHAPTER IV

ENVIRONMENTAL RESISTANCE

Environmental resistance is the sum of all the factors in an environment that tend to reduce the rate of insect multiplication The factors which are combined to produce this force, so far as forest insects are concerned, may be divided into four principal groups. physical, nutritional, plant physiological, and biotic These groups will be considered separately

PHYSICAL FACTORS

Perhaps of all the limiting factors of the insect's environment the physical group has received the most intensive study and is best understood. But the knowledge of even this group is still far from complete It is known in general that temperature plays an important rôle in determining the rate of insect development and also the possible distribution of all insects, but there are comparatively few species the temperature reactions of which are definitely known Likewise, the effects on all species of light, moisture, air movement, and all the other factors that are thought of in connection with climate and weather are far from fully understood Nevertheless, much important progress has been made along these lines. In the following pages some of the more important effects of the action of these physical factors upon insect activities will be discussed

Temperature.—One of the most important physical factors that regulates insect activity is temperature. Each species of insect has a definite range of temperature within which it is able to live. Temperatures above or below this range result in the insect's death Near the upper and the lower endurable limits are the dormant zones in which all external movement ceases When an insect is in the lower of these zones, it is said to be in hibernation; when it is in the upper zone, it is said to be in a state of estivation Between these dormant or lethal zones lies the zone of activity or, as it is sometimes called, the *zone of effective temperature.*

As the temperature rises above the zone of hibernation in the effective zone, it becomes more and more favorable for insect development until an optimum point is reached. As the temperature rises above the optimum, conditions become less and less favorable, until all activity ceases when the zone of estivation is reached

The temperature requirements of insects vary with the species Some species are active at a temperature only slightly above the freezing point of water, whereas most species are active only at

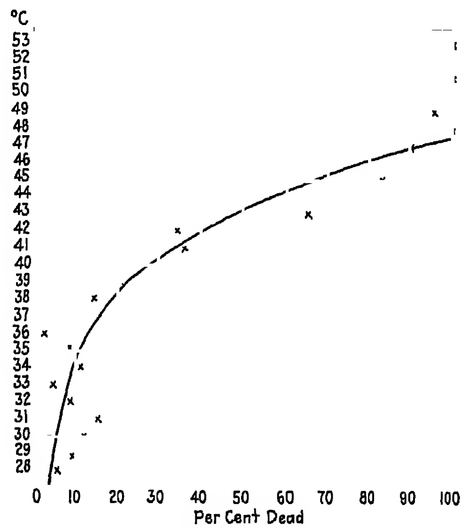


FIG 16.—Graph illustrating the effect of high temperature upon adults of the balsam-fir bark-beetle, *Pityokteines sparsus* The temperatures are subcortical and are, of necessity, only approximate Practically none of the beetles are able to survive a temperature higher than 48° C

temperatures above 15° C The optimum temperature for most insects is in the neighborhood of 26° C., and estivation usually begins at from 38 to 45° C For many insects, 48° C. (Fig 16) is the point of fatality at high temperatures although some of the heat-resistant forms, for example Chrysobothris, can endure a temperature of 52° C for a short period (Graham, 1922). The low fatal temperature varies both with the species and with the season. It has been shown that the same species is able to endure much more cold in the fall and winter than in the spring and summer (Payne, 1926). The width of the zone of hibernation is

so variable that no general statement regarding the usual point of fatality at low temperature can be made. All that can be said is that tropical species are, as a rule, much more susceptible to cold than are the temperate species

This brings us to a consideration of the influence of temperature factors upon the distribution of insects. Several more or less successful attempts have been made to determine life zones on the basis of the sums of effective temperatures for different localities. Merriam (1898) used this basis for the construction of the life zones that are generally used in biological work (Fig. 17) Sanderson (1908) has shown, however, that insects do not always occur in every locality where the total of effective temperature is sufficient to make possible their complete development Thus even though there may be a sufficiency of warm weather in the summer, a species may be kept out of a locality as a result of extremes of cold in the winter For instance, the northward distribution of the gypsy and the brown-tail moths is definitely limited by low winter temperatures (Summers, 1922), and it is probable that owing to this neither of these insects will ever reach the northernmost point at which summer temperatures are favorable.

A very useful empirical law has been developed by Hopkins (1920 and 1921) which is known as "Hopkins bioclimatic law." By the use of this law it is possible to prophesy from known conditions in one locality what conditions will exist in another locality. According to this law any periodical biological phenomenon—such as the emergence of insects from hibernation, the spring awakening of vegetation, or the entrance of insects into hibernation—is correlated with latitude, longitude, and altitude. The law may be stated as follows: Other conditions being equal, the variation in time of any periodical event in temperate North America occurring in the spring and early summer is at the general rate of 4 days later to each degree of latitude northward, or 5 degrees of longitude eastward, or 400 feet of altitude upward. In the late summer and fall, conditions are reversed This law appears to hold reasonably well for at least those portions of temperate North America east of the Rocky Mountains. Consideration of this law shows clearly that, on the basis of temperature alone, a high mountain range might prove an impassable geographical barrier to the spread of animals or plants from one region to another.

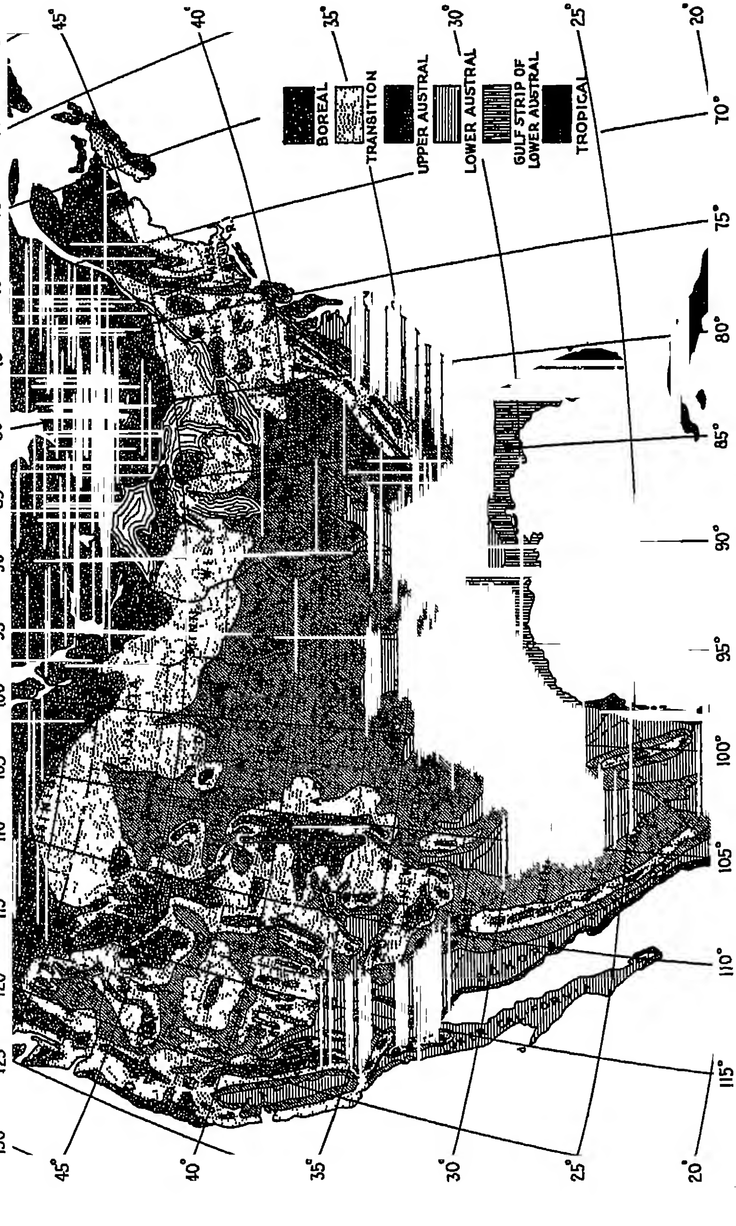
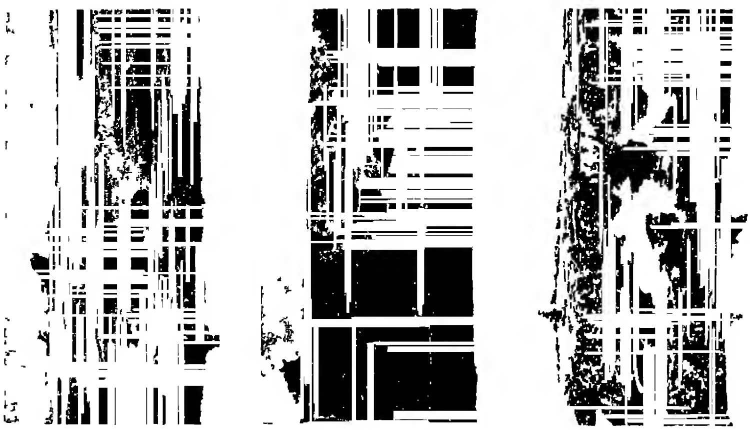


FIG. 17.—Life zones of Merriam (*Biol Survey, U S. Dept Agr.*)

In the preceding discussion we have seen how temperature limits the geographical distribution of insects. It also limits with equal certainty the local distribution of these forms of life. The local temperature varies greatly within very short distances. For instance, on a bright day in summer the temperature at the surface of the ground may be as much as 50° C higher than the air temperature at breast height A difference of from 10 to 20° C between surface temperature and the temperature one foot above the surface is not at all uncommon With such a



A B C

FIG 18 —Variations in the amount of insect work on three sides of a white-pine log lying in full sunlight A shows the sterile zone on the top side where high temperatures prevail B shows the bottom side which is too moist and cool for many insects C shows that on the side section, where conditions are ideal for the maximum number of species, insect galleries occupy most of the area

wide range within such a limited space, it is possible for many insects to change their position so as to keep within a favorable zone (Chapman, 1925).

Some insects, those living in logs for instance, are unable to move quickly from place to place If they happen to be working on the upper side they cannot move away from that location in the event that conditions become unfavorable. Likewise, if they are working on the lower side they must face what comes in that location. If conditions become sufficiently unfavorable the insects may be killed (Figs 18*a*, 18*b*, and 18*c*). In logs having comparatively thin dark-colored bark the side exposed to direct solar radiation may reach 60° C or more (Graham, 1922 and

1924) (Fig 19). Such temperatures are far above the fatal point for all insects, and so on the upper side of logs lying in the sun there is usually a sterile zone. On the sides where lower temperatures prevail, the insects occur in greatest numbers; while on the lower side, where uniformly cool conditions are found, there exist only those species that are able to live under cool conditions The fatal effect of high temperature upon log-

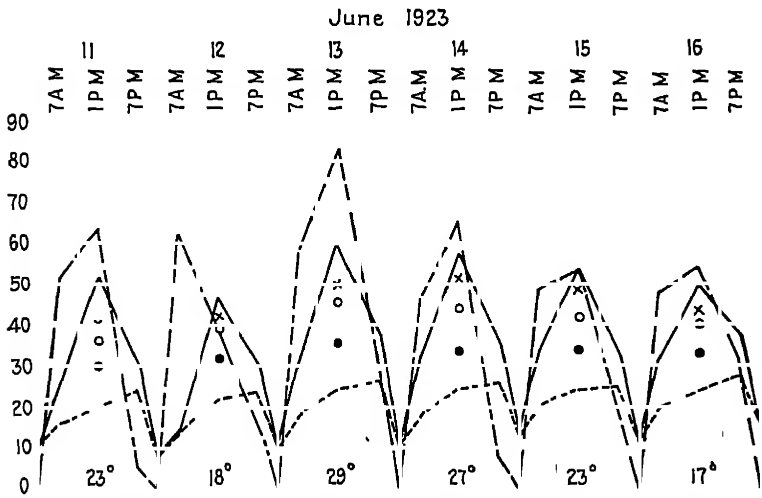


FIG 19 —Graph illustrating the daily fluctuation of subcortical temperature, expressed in degrees Centigrade, on the upper side of white-pine logs lying under different light conditions Subcortical temperature in full sun is represented by the solid line, in full shade by the short dashes The subcortical temperatures at noon for logs in two-third sun, one-half sun, and one-fourth sun are indicated by the cross, the circle, and the dot, respectively Daily fluctuations in subcortical temperature are due chiefly to fluctuations in air temperature and light intensity. Air temperature at noon is indicated in degrees Centigrade along the bottom edge of the graph, light intensity by the broken line Note the variation in the effect of these factors under different shade conditions

inhabiting insects is made use of, as will be shown later, in insect control

Temperature not only affects the geographical and local distribution of insects but it also regulates the rate of insect development In general, the rate of development increases in proportion to the increase in temperature until the point of optimum temperature is reached The rate of this increase varies somewhat at different temperatures and with different species, but, in general, an increase of 10° C doubles the rate of development Sanderson and Peairs (1913), Peairs (1927),

Krogh (1914) and other workers have expressed the increase in velocity of development more accurately, stating that the rate of development increases directly with the temperature, the developmental curve being a segment of a true mathematical hyperbola Since the reciprocals for the points on an hyperbola fall, by definition, in a straight line, then if we plot the reciprocals of two points and connect them by a straight line, it will be possible to compute the rate of development at any other point. Above the optimum point a reduction in rate of development occurs with increasing temperature until at a high temperature the rate of development is reduced to zero

Light.—The reactions of insects to light are not very different from their reactions to temperature and, since these factors are usually closely associated with one another, and since they generally vary synchronously, it is often difficult to determine whether the effects are produced by the one or by the other.

Theoretically, it seems possible to divide light, just as we do temperature, into optimum, effective, lethal, and fatal zones In as much as all insects respond either positively or negatively to light, it may be assumed that the optimum condition varies greatly with different species. The stimulating effect of light on certain species is well illustrated by the reaction of Chrysobothris adults These beetles remain inactive on cloudy days when the air temperature may be as high as, or higher than, the temperature on some sunny days when they are active Carpenter (1908) has shown that the convulsive motor reactions of Drosophila, which normally occur at a temperature of 39° C , appear at 30° C. under the rays of a strong light of 480 candle power Although certain insects are not able to endure strong light, it seems probable that light under natural conditions rather seldom goes beyond the limits of toleration of most species It is true, however, that the presence or absence of light determines to a greater or less extent the local distribution of insects Those that are positively phototropic or heliotropic will be found for the most part in the open, whereas those that respond negatively will be found in the soil, under rocks or bark, or in some other dark location In some instances light appears to be an important factor in determining the place of oviposition of certain insects. For instance, Chapman (1915) has shown that the two-lined borer, *Agrilus bilineatus*, deposits its eggs by preference upon trees exposed to full sunlight (Fig 20). This is apparently

also true of the bronze birch-borer, *Agrilus anxius*. From this discussion we see that light is difficult to separate in its effects from temperature, but there is good evidence to indicate that this factor is important in the life of insects.

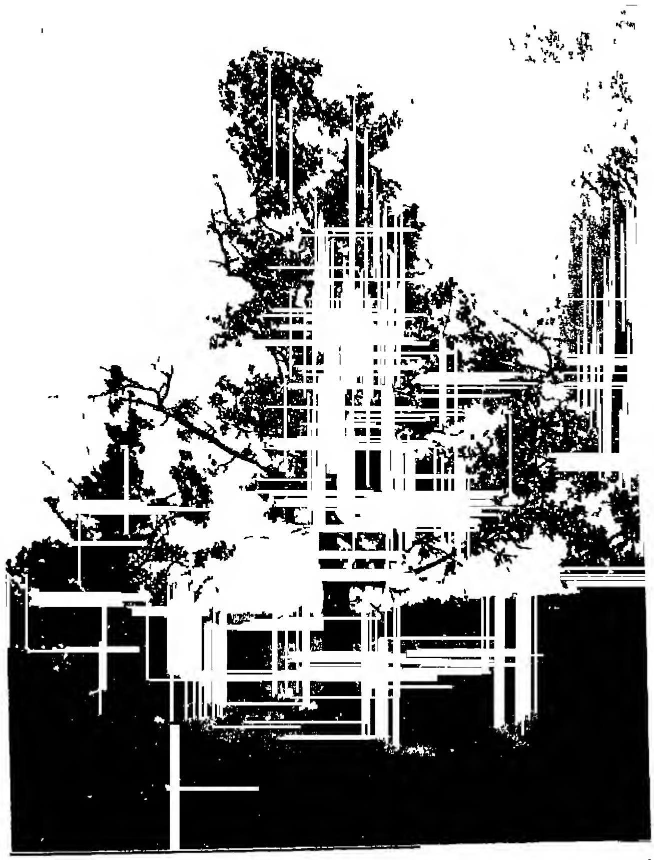


FIG 20—Red oak trees standing in full sunlight are especially susceptible to injury by Agrilus (*University of Minnesota*)

Moisture.—Another physical factor of the environment which plays an important part in insect activity is moisture As with all other forms of life, so it is with insects. both their distribution and development are dependent on the presence of water in the environment The effectiveness of heat in stimulating or retarding the velocity of insect development is also influenced by the

amount of moisture present. Under favorable moisture conditions an insect is not as susceptible to extremes of temperature

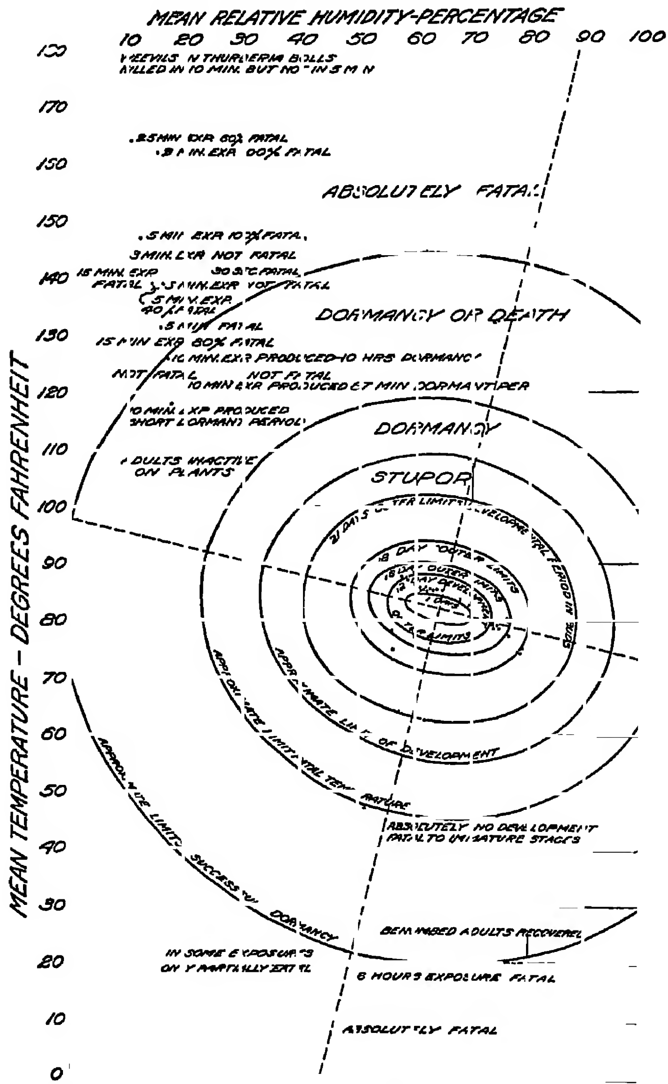


FIG 21 —Graph showing the combined effect of temperature and relative humidity upon the activity of the cotton-boll weevil (*Bureau of Entomology, U S Dept Agr*)

as it would be under unfavorable moisture conditions (Pierce, 1916) (Fig 21)

With moisture, as well as with temperature, each species has definite requirements with optimum and effective zones The extreme zones (lethal or fatal) are less clearly marked than is the case with heat. Under ordinary conditions, an excess or deficiency of moisture does not result in an insect's immediate death but only in a disturbance of its activities. There are, however, certain outstanding instances of forest insects that are definitely limited in their activities by the moisture factor. The powder-post beetles, for instance, cannot live in moist wood (Snyder, 1926), whereas the ambrosia beetles cannot develop in dry wood The rate of development of other wood-boring species may be greatly reduced by the desiccation of the wood. In fact, there are cases on record in which a wood borer having a normal life cycle of 1 or 2 years has required, because of unusually dry conditions, 20 years or more to reach maturity

Climate and Weather.—In view of the important effect that any one of these factors of temperature, light, or moisture may have on the life of forest insects, it is evident that, when all three are combined and joined with still other factors the resulting complex, which we call weather or climate, must be of fundamental importance in considering forest insect problems Climate is the result of the combined action of all the physical factors of the environment over a long period of time and, so far as meteorological evidence is concerned, appears to be relatively stable in the same locality It forms the basis of Hopkins' bioclimatic law and of Merriam's life zones

Weather, on the other hand, is the result of the combined action of all the physical factors of the environment at any given time, and it varies from hour to hour, day to day, and week to week It influences the abundance of insects and the rate of development from year to year, and from season to season, in every locality With insects of the forest, as well as with others, weather conditions are exceedingly important in regulating abundance A late frost in the spring after the eggs of the forest tent-caterpillar have hatched may result in the starvation of almost all the young larvæ of that species (Blackman, 1918). The same thing is true of all leaf eaters that feed upon deciduous trees Heavy rains during the larval stage of insects that feed on the exposed surfaces of trees may wash off and destroy large numbers of such insects and thus reduce the possibility of their becoming epidemic Cool weather during the develop-

mental period may so lengthen the larval or nymphal stage that a much larger proportion of the species may fall prey to their enemies than would otherwise be the case. Also moist warm weather may make possible outbreaks of entomophagous diseases On the one hand, dry weather may so reduce the vegetative growth of trees on which certain species feed that great injury results from the activities of only a normal number of pests, or, on the other hand, an unusually luxuriant growth may overcome effects of an insect attack that might in the average season produce great injury to the trees. In the case of most defoliating insects, high temperatures combined with light rainfall tend to favor insect development and to encourage outbreaks

The various physical factors discussed above may be much better understood than any of the other limiting factors of the insect environment, but it would be erroneous to assume that there are not other factors equally important entering into environmental resistance These will be discussed under the headings of nutritional, physiological, and biotic factors

NUTRITIONAL FACTORS

The physical factors of the environment do not lend themselves to regulation, whereas the nutritional factors may often be controlled with a reasonable degree of exactness. If the food conditions can be so controlled that outbreaks of pests are improbable even with weather favorable for insects, then we can cease to disturb ourselves concerning the effects of weather upon the rate of insect multiplication For this reason, if for no other, we should be particularly interested in the nutritional factors

Quantity of Food.—It is an accepted biologic law that, other things being favorable, an organism will eventually multiply to the limit of its food supply. As a rule, the more numerous the individuals of a tree species, the more abundant are its insect enemies When there is an unlimited and convenient supply of a certain species of trees, then the stage is set for an outbreak of the insect pests of that tree.

The spruce budworm outbreaks in eastern United States and Canada, as will be shown later, are associated with an overabundance of balsam fir, and possibly white spruce (Figs 22, 23). Similarly, the larch sawfly outbreaks have undoubtedly been stimulated by large volumes of tamarack, and forest tent-caterpillar outbreaks by extensive stands of poplar or

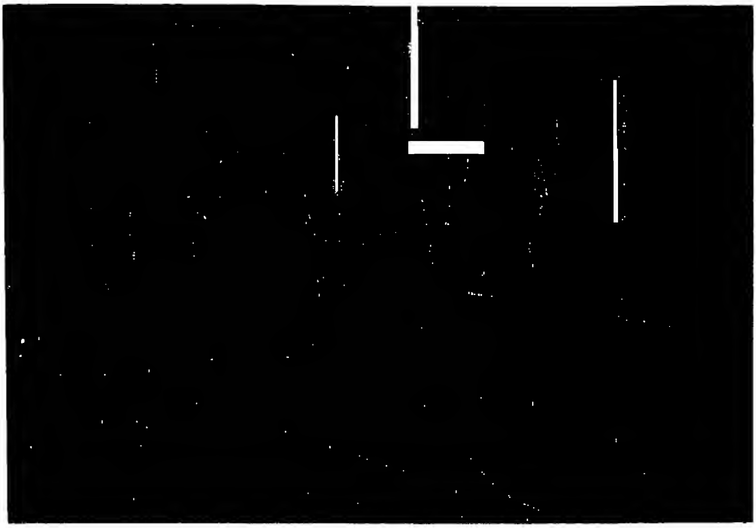


FIG 22 —A portion of the Superior National Forest heavily injured by the spruce budworm Balsam fir was the predominant tree in this forest and was almost completely destroyed Most of the standing trees in the background are dead except the birch which was overtopped by the balsam fir

FIG 23 —A mixed forest of pine, spruce, fir, and hardwoods in the same region as that shown in Fig 22 Although surrounded by a heavy spruce-budworm outbreak this forest suffered comparatively slight injury

other suitable food trees Our forest and shade trees are often listed according to their susceptibility to insect attack. On examination of these lists it is found, with rare exceptions, that the species listed as insect resistant are those which do not occur commonly in large masses. Norway or red pine is usually classed as insect resistant but accurately speaking it cannot be said that this and similar species are any more resistant than other species Their apparent resistance is due to their relative

FIG 24 —A jack pine more than 80 per cent defoliated by the spruce budworm and the jack-pine sawfly working together This sort of injury is common where jack pine occurs over large areas.

scarcity in the forest. It is quite certain that if the proportion of these species were greatly increased, some of the many insects that now occur upon them in innocuous numbers would become serious pests

At one time, jack pine was regarded as an insect-resistant species, but now it is being seriously attacked by a number of dangerous pests (Fig 24). The reason for this apparent change in susceptibility may probably be explained by the fact that in the range of the jack pine this species has largely replaced the

white and norway pine which a few years ago formed the major portion of the virgin forest in the Lake States This has meant a tremendous multiplication in the quantity of jack pine Today instead of only scattered blocks of jack pine on lands too poor to support other species, we have vast areas over which this species is predominant Thus the quantity of food available becomes an important factor in regulating insect abundance

Kind and Quality of Food.—The abundance of forest insects and the length of the developmental period are also limited by the

FIG 25 —Work of the spruce budworm on a young jack-pine shoot The larvae of this insect must complete their growth while the young needles are soft and succulent

kind and quality of food which they are able to use An insect species, for instance, that feeds only on the succulent tissues of the cambium region must complete its feeding period quickly while the perishable material upon which it feeds is still in usable condition Although perishable, this food is comparatively high in food value We should expect, therefore, that the cambium region would be filled with an abundance of insects, each with a short developmental period, and this is exactly the condition that exists there.

By the nature of their food, leaf-eating species are, with a very few exceptions, limited to a single season or even to a short part of one season for their development Few leaf eaters can pass the winter as partly grown larvæ; consequently they must complete their development before the leaves drop in the autumn In some cases the length of the developmental period is limited to a few weeks during which the foliage is soft and succulent (Fig 25).

With the wood borers, on the other hand, feeding as they do upon a medium that changes very slowly it is not at all uncommon to find their life cycle extending over several years. Many of the wood-boring species, like some of Cerambycidæ and Buprestidæ, feed for a time in the cambium region before entering the solid wood. In this way the young larvæ are provided with more nourishing and more easily digestible food than are the larger larvæ This suggests that the powers of digestion of these species are better in the later than in the earlier stages. Other insects, like the Siricidæ, are able to digest solid wood from the earliest stages and are exclusively eaters of solid wood

On the basis of these facts, it is seen that all tree insects do not have the same food requirements some require leaves, some find the cambium region to their liking, and still others are able to wrest their living from the solid wood As the wood is worked over by insects and fungi, its chemical and physical character changes, and with this change new species of insects replace those which attacked the living tree or recently cut log These in turn are replaced by others until in the last stage of decomposition the population is identical with that of the duff stratum of forest soils Thus there is a continuous succession of insect species inhabiting the tree from the fresh green condition of the newly felled or killed tree to the completely decomposed condition

During the process of disintegration there is, in many instances, a close relationship between fungi and insects In some cases, particularly in the early stages, a true symbiotic relationship can be demonstrated (Baumberger, 1919). Just as the fruit flies can develop normally only where bacteria or fungi are present to aid in the elaboration of raw food so in the case of many wood borers, fungi must be present to alter the character of the wood thereby making the food materials available for the insects In some cases, like that of the ambrosia beetles, the fungus furnishes the entire food of the insect, and the galleries that are

cut into the wood by the insects serve only for shelter and a place for the food fungus to grow

Host Selection.—Most species of forest insects are limited in their feeding either to one species of tree or to a more or less prescribed group of species. The locust borer, for example, feeds only on the black locust, the sugar-maple borer attacks only maples, the larch sawfly defoliates only larch, the Nantucket pine moth infests only the pines, the spruce budworm is confined to a comparatively limited group of conifers

When an insect attacks only one species of tree, its control presents a comparatively simple problem, but when it is a general feeder, like the gypsy moth, the problem becomes much more complex Fortunately with many species that feed on a variety of hosts the problem is simplified by the fact that there is a strong tendency for an insect to oviposit on the host upon which it was reared This is called Hopkins' *host-selection principle* (Craighead, 1921), and it apparently holds true for many of the Cerambycidæ and for some Ipidæ Preliminary evidence indicates that it holds true within certain limits for the spruce budworm. Further work along this line may show that this principle may be applied much more generally than is now known to be the case

Perhaps the operation of this principle has in the past ages given rise to new species by developing first biologic varieties limited to a single host and later to forms distinct morphologically as well However this may be, whenever host selection occurs control measures are simplified thereby, because each biological variety may then be treated as if it were an individual species

PLANT PHYSIOLOGICAL FACTORS

Trees possess certain physiological characteristics which result in producing, in varying degree, a certain real ability to resist insect attack. These characteristics, by making environmental conditions less favorable for the insect than would otherwise be the case, increase the force of environmental resistance working against the insect

Rapidity of Growth.—Vigorous trees growing rapidly suffer less from insect injury than do trees of the same species that are growing more slowly Rapid growth has a double effect in that it actually makes the tree more resistant to both attack and

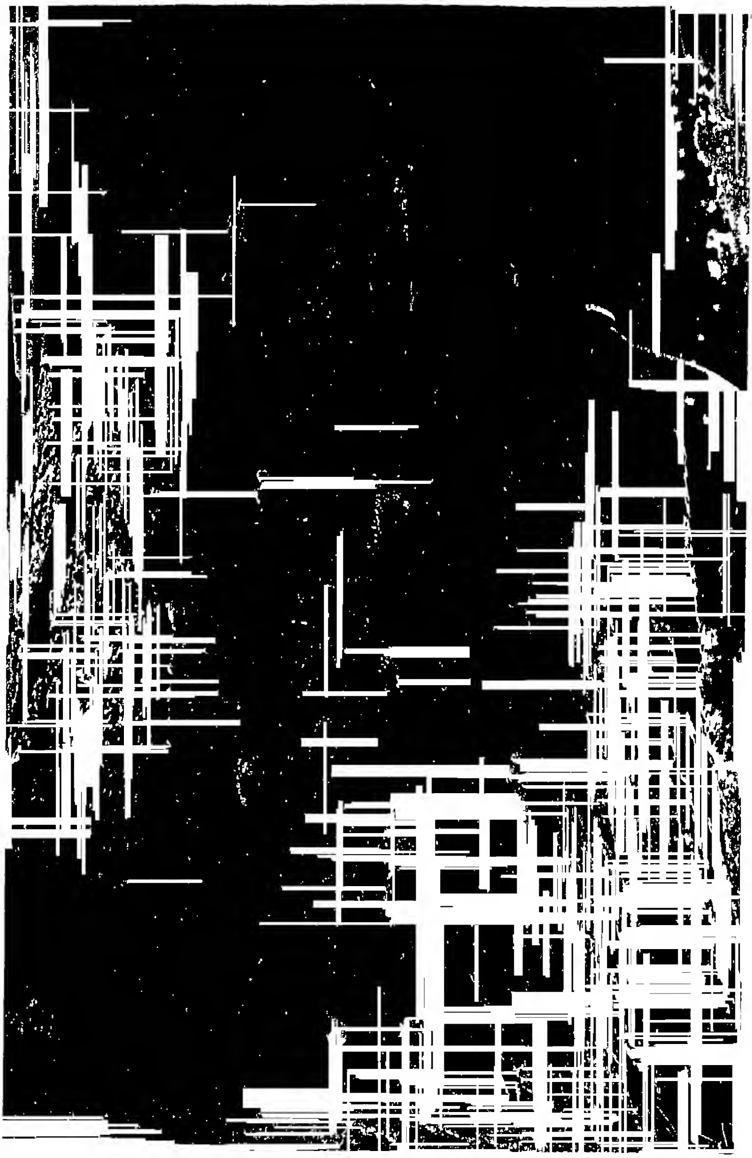


FIG 26 — Pitch tubes on a western yellow pine that has been attacked by *Dendroctonus brevicomis* (*Entomological Branch, Can Dept Agr*)

injury. The more rapidly a tree grows, the shorter will be its period of exposure to the series of pests that may attack it during the various stages of its growth. This shortening of each of these stages is in itself a form of resistance, but the rapidly growing tree exhibits still other characteristics that make it less susceptible to attack than its slower growing and less vigorous brothers.

One of these characteristics is the copious flow of sap, or resin, that exudes from wounds of fast growing, vigorous trees This flow of resin will drive out, or overwhelm and kill, almost any of the cambium borers, before they can become established in the tree Such a tree, except when it is attacked simultaneously by large numbers of these insects, is able to resist attack successfully In forests where Dendroctonus beetles are working, it is not at all uncommon to find trees that have successfully repelled attack, even in the areas of heaviest infestation. Such trees are usually covered with "pitch tubes," formed by hardened resin that exuded at each point of attack (Fig 26). On examining these trees the beetles will be found entombed in some tunnels in the mass of resin filling their galleries while other tunnels will be deserted

Other interesting examples of resistance to attack by vigorous growth may be cited For instance, some of the buprestids sometimes deposit their eggs upon trees that are fairly thrifty. These eggs will hatch and the larvæ will penetrate into the bark. In order to develop, these larvæ must feed in the cambium for a time at least, but they can feed only on the cambium of decrepit trees or freshly cut logs Therefore when they reach the cambium layer of a healthy tree they are forced to turn back into the bark because they are unable to find suitable food and there they die a lingering death These small buprestid larvæ frequently have been found starving in the bark of healthy jack-pine trees

Foliage Characteristics.—Sometimes a tree species may resist insect attack because of certain characteristics of its foliage. The lack of synchronization between the spruce budworm and the black spruce illustrates well this kind of resistance. A detailed discussion of this relationship will be taken up later, but it deserves mention here because it illustrates one type of physiological resistance When the young budworms emerge from hibernation they require tender fresh foliage for food

Their time of emergence is about 2 weeks prior to the opening of the black-spruce buds, consequently in a stand of pure black spruce the larvæ are faced with a food shortage in the early part of the season. Some of them will find the green tissues that they require by boring into a bud, but many of them will fail to do this and will perish. Thus the black spruce is able to reduce budworm abundance.

The white spruce also has a means of reducing the number of budworm larvæ feeding upon it. Unlike the black spruce the buds of the white spruce open at a time suitable for the budworm, but the white spruce needles harden and become unpalatable before all the larvæ reach full growth. Many of them perish when they are forced to leave the trees on which they have been feeding to seek more suitable food Still another illustration of how a foliage characteristic may prevent the attack of an insect is the way by which the European-elm miner is prevented from attacking the American elm. The leaves of our native elms are much thinner than those of the European species and do not provide enough space to accommodate the miner.

Distasteful Characteristics.—Certain trees apparently possess immunity from insect pests because they are unattractive or actually distasteful to the insects. Just what these characteristics really are is not known but that they exist cannot be doubted. They are often not possessed by all the individuals of a species in the same degree. Some trees may be practically immune to attack while a neighboring tree will be highly susceptible.

A striking example of the variation in this respect is to be observed in a certain plantation of norway spruce in the Saginaw forest, one of the forest properties of the University of Michigan. This plantation has been rather heavily attacked by an adelgid, often called the "spruce-gall aphid." Many of the trees are heavily attacked while others are absolutely untouched Even when the branches of an immune tree interlock with those of a heavily infested tree, the immune tree will remain uninfested

It is said that certain individual spruce trees in Europe show a decided resistance to the attack of that much dreaded forest defoliator, the nun moth. The larvæ refuse to feed upon the needles of these resistant trees but, according to Prell, when branches are cut and placed in water for 24 hours, they will then

be accepted as food. This may indicate that some volatile repellent substance not present in other trees of the same species constitutes the active agency that prevents the insect from attacking these resistant individuals

BIOTIC FACTORS

The last of the environmental factors tending to limit the multiplication of forest insects are biotic factors In this group are included all the interrelations existing between the various living organisms in an environment that result in a limitation of multiplication The biotic factors that play important roles in environmental resistance are competition, predators, and parasites

Competition.—It is possible for competition to occur either between the individuals of the same species, or between different species The final result in either case is a reduction in the rate of multiplication of the insects concerned. Among insects there is continually going on a strenuous competition for food, space, and shelter. Of these three, competition for food probably ranks first in importance. There is, normally, a continuous and abundant supply of food for all the insects in a forest as long as no insect is present in epidemic numbers In order that a continuous supply of food be available, only a comparatively small part of that which is in existence at any one time can be used. Food must be produced more rapidly than it is consumed or the supply will eventually be cut off This means that a forest can afford to supply other organisms with only that amount of food which it is able to produce in excess of its own requirements for maintenance and growth If the amount of food taken exceeds this surplus amount, the balance between production and consumption will be temporarily disturbed Thus under normal conditions the insects are using only this surplus and not the entire available supply At such a time we cannot say that there is any real competition for food in as much as other forces of environmental resistance are holding down the number of individuals to a point where an abundance of food for all exists.

At a time when some insect species may succeed temporarily, at the expense of the other forms of life in the forest, in increasing its numbers to a point where an out-break may be said to exist, the situation is then changed. Then the insects are no longer

feeding only on the surplus but are actually using up the capital, which should be reserved for maintenance and for growth. Under such conditions a keen competition, chiefly between the individuals of the same species, is brought about There can only be one result: sooner or later, if the insect outbreak is not checked by the action of some outside controlling influence, the entire supply of food will become exhausted The trees having been killed, the insects that are dependent upon them for their food either starve or are forced to migrate to new locations Thus competition for food has reduced their numbers

FIG 27 —White-pine weevil larvæ lying side by side as they work downward beneath the bark of the shoot in which they are feeding Space limits the number that can feed in this way

Competition for space is an important limiting factor among some groups of forest insects, whereas with other species it is of little importance This type of competition is sometimes very keen among the cambium insects and also among the wood borers. For instance the number of white-pine weevils that can reach maturity in a terminal shoot of a pine sapling is directly proportional to the circumference of the shoot (Graham, 1926). This is due to the feeding habits of the larvæ. A single larva working alone would be quickly overwhelmed by the resin that would be exuded into its tunnel by a healthy shoot and would be killed. In order to avoid such a fate the larvæ of the weevil work downward side by side, completely encircling the shoot As they increase in size they become more and more crowded with the result that the weakest larvæ are forced out of line and left to starve, while the strongest forge ahead and are in a short time overwhelmed by resin The number of full-grown larvæ surviving cannot be greater than the number that can lie side by side around the shoot (Fig 27) Many bark beetles of the family Ipidæ are limited in a similar way Usually competition is

between larvæ, but occasionally in cases where all stages of an insect are living in a limited environment, as do the bark beetles and ambrosia beetles, there may be competition between adults and larvæ.

Sometimes the abundance of forest insects is limited by competition for suitable shelter. The abundance of termites or of carpenter ants is definitely limited in certain instances by a scarcity of suitable places to build their nests With most forest insects, however, if food is sufficient, shelter is also available, in as much as in the majority of cases the insect's shelter

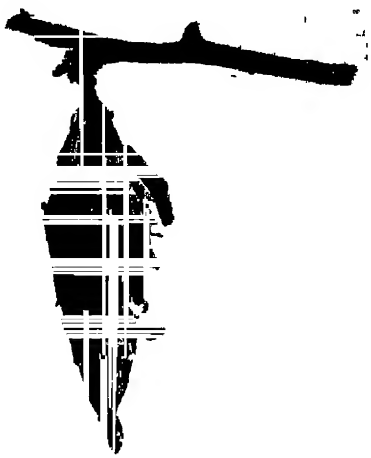


FIG 28 —A typical bag of the evergreen bagworm This bag is constructed of silk, spun by the insect, combined with bits of leaves and twigs (*Bureau of Entomology, U S Dept Agr.*)

is built either of the food upon which it feeds, or of secretions from its own body, or of a combination of the two (Fig. 28).

Predators and Parasites.—The effect of predators and parasites in producing environmental resistance is so nearly identical that it seems advisable to discuss them together in order to avoid repetition These two closely allied factors constitute an important part of environmental resistance. In fact some authorities feel that they are more important than all the other factors combined. Most others, however, do not agree with this estimate of their importance (Howard, 1926) but all agree that without these limiting factors almost all insect species would be much more abundant than they now are.

Both parasites and predators feed upon insects The chief distinction, in entomological usage, between them is that a

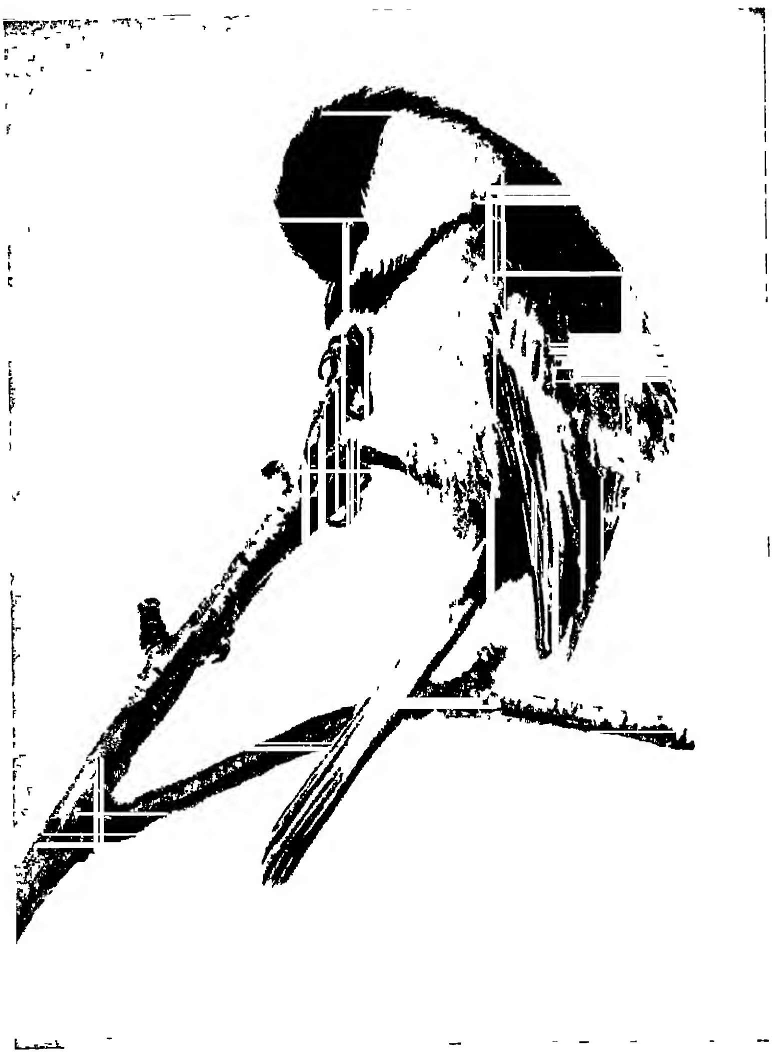


FIG 29—A chickadee searching for insect eggs (*New York State College of Forestry, Syracuse University*)

parasite obtains its food from a single organism of another species, the host, whereas the predator feeds upon a series of

victims, the prey. A parasite, according to the generally accepted definition, obtains its food from its host without killing the host directly In entomological usage, on the other hand, the host is usually killed The predator, however, always kills the prey upon which it feeds Among the important parasites of insects are representatives of many groups. fungi, bacteria, protozoa, various arthropods including insects, nematodes, and other organisms Of all these, insect parasites of other insects have received most attention from entomologists Predators, like parasites, have representatives among many groups of animals Some of these are birds, mammals, reptiles, amphibians, and not the least important, other insects No stage in the development of an insect is free from the attack of predators and parasites.

Even though the eggs of insects are generally very small objects, they nevertheless have both their predaceous and parasitic enemies. No matter how carefully they are hidden away some of them are almost certain to be found and destroyed. Insect eggs furnish a staple item of diet for nuthatches and chickadees (Fig 29) After watching one of these insectivorous birds searching the trunk and branches of trees especially during the winter, it is easy to believe that they are extremely effective in reducing the number of insects which pass the winter in the egg stage

The eggs of insects are attacked by parasites as well as by predators Even the eggs of small moths, like the pine tip-moth, are sufficiently large to provide food enough for the development of a tiny parasite. During 1926, in the Bessey Plantations at Halsey, Nebraska, about 60 per cent of the summer generation of eggs were parasitized Careful examination of the eggs of aphids, tussock moths, tent caterpillars, or almost any other species will reveal the fact that many eggs that have failed to produce larvæ are perforated by the exit hole of one or more egg parasites

In spite of the activity of both predators and parasites in destroying the eggs of insects, there is usually an ample supply of larvæ produced to cause a decided increase in the insect abundance if they were all to complete their development. But in the larval stage, also, predators and parasites operate in such a way as to hold down the rate of multiplication Even the larval stages of wood borers, well protected though they are by the

wood in which they are tunneling, are not safe. The woodpeckers dig them from their tunnels; some of the ichneumon flies (Fig. 30), by inserting their long ovipositors through the wood, succeed in parasitizing them; and some of the predaceous beetles follow them into their tunnels and there destroy them

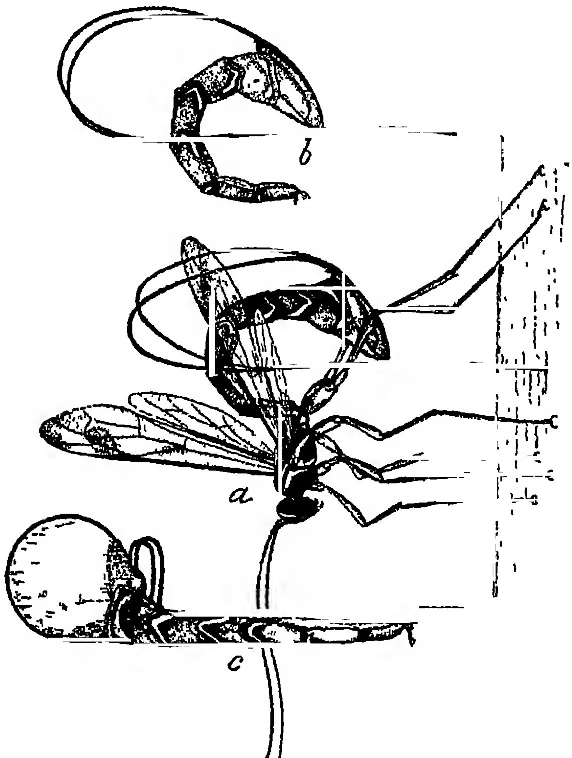


FIG. 30.—*Megarhyssa (Thalessa) Lunator*, one of the largest of the ichneumon flies a pictures a female in the act of parasitizing a wood-boring larva b and c show the details of the ovipositor. (*Bureau of Entomology, U S Dept Agr*)

Larvæ of defoliating insects, and other insects on the surface of plants, because of their comparatively exposed position, are attacked by a host of enemies too numerous to mention. Insect parasites, predaceous insects, and birds all take their toll. When the larvæ drop to the ground either accidentally or, as many do, to prepare for the pupal stage they expose themselves to the attack of the terrestrial predators Shrews, mice, and skunks are all very fond of insect food and seize hungrily upon any larvæ

that they find. Ants, also, are not averse to insect food and feed on small larvæ. The greatest reduction in insect numbers by predators and parasites probably occurs during the larval period

Insects usually seek secluded places for pupation and many spin cocoons to protect them during this quiescent period. But careful as they may be to hide or protect themselves, many of them will be found and killed Parasites of the pupal stage are not common Predators are, however, sufficiently plentiful. Insectivorous birds and insects feed upon the pupæ above ground and small mammals, for example shrews and mice, dig up and eat those in the ground.

Adult insects are attacked by parasitic mites, nematodes, and other parasites but do not usually succumb to the attack of these animals How much injury the insect suffers from these organisms is not known, but it is quite probable that they are injured to some extent by them Insect parasites of adult insects are rare. Predators, particularly vertebrate predators, constitute the most important biotic factor of environmental resistance in so far as adult insects are concerned. In addition to the vertebrate predators, however, predaceous insects and spiders kill many adult insects

From the foregoing discussion it is evident that, in as much as predators and parasites attack insects in every stage of their development, they are important factors of environmental resistance.

CHAPTER V

INSECT ABUNDANCE

The importance of insect abundance lies in the fact that the ability of any one insect species to injure trees depends primarily upon the numbers of that insect in a forest

BIOTIC BALANCE

Many insect species in every forest area feed upon the trees, but never occur in sufficient numbers to cause appreciable damage. On the other hand, there are some species that occasionally become extremely abundant and injurious The latter are the insects that we usually regard as forest pests, the former are disregarded.

Nature's Deadlock.—It must be admitted that every insect which can successfully attack a living tree is potentially a menace to that tree Fortunately, however, under normal conditions no insect species is allowed to multiply so rapidly that it occurs in sufficiently large numbers to be a menace to the trees upon which it feeds It is only under abnormal or unusual circumstances that insects become epidemic. Normally, the numbers of the various organisms in the forest remain approximately constant from year to year This is because all of the elements of the forest environment are usually so balanced one against another that no species can gain much advantage over its associates Thus in the struggle for supremacy between the different forms of life there is a deadlock Under such conditions, although the forest may be occupied by numerous potential pests, none will occur in sufficiently large numbers to endanger the welfare of the trees. This static condition is known as the state of *biotic balance.* The importance of this equilibrium cannot be overemphasized It is only under such a balanced state that long-lived organisms are able to exist at all The life of a tree extends over a period of a hundred years or more; sexual maturity is only attained after many years of growth Such long-time processes, obviously, presuppose generally stable environmental conditions

The factors reacting to produce the balanced condition which normally exists between any insect species and the various elements of its environment may be divided into two opposing groups, which, under balanced conditions, are equal and opposite forces On the one hand is the ability of the insect to reproduce itself in a given time under ideal conditions, or its biotic potential, on the other hand is a group of factors that limits or checks the insect in its rate of reproduction and prevents it from realizing its potentiality of multiplication or, as we term it, the environmental resistance.

Abundance and Environmental Factors.—The relationship that exists between these two great opposing factors in the production of insect abundance has been expressed by Chapman (1925) by means of a simple mathematical formula in which if C represents insect abundance, BP biotic potential, and ER environmental resistance then $C = \frac{BP}{ER}$ Whether or not this formula will stand in its present form can only be determined by future investigations. In the following discussion, in order to avoid cumbersome duplication, the letters of the above formula will be used to stand for their respective terms

Now if it is assumed that for any one species C is to remain practically constant from year to year, as would be the case under conditions of biotic balance, let us see what must happen if changes were to take place in the environment Since BP—as shown in Chap III—is a constant for any species, it follows that whenever a change occurs in one set of factors in ER, it would have to be offset by comparable changes in other factors of ER or else C would not remain constant. For example, if an increase occurred in the available food supply of an insect, there would have to be corresponding compensating changes in some of the other factors of ER if C is to remain unchanged

Occurrences in connection with studies of the jack-pine sawfly made by the author in Minnesota furnish excellent illustrations of this point. These will be discussed later in detail under defoliators but it seems appropriate that they be mentioned briefly here. Due to an increased quantity of jack pine growing in pure stands, food conditions for this insect have in recent years become ideal; in spite of this, during the past few seasons the number of jack-pine sawflies has remained approximately constant as the result of increased physical and biotic resistance of

the environment For two seasons a combination of unfavorable temperature and a parasitic disease held down the number of these insects, another year heavy storms at a critical time prevented their increase, and in still another season a late frost was the most important agency of resistance.

In the preceding illustration the abundance of a certain species in one locality was kept approximately constant over a period of years. This constant number was maintained in spite of a changed *ER*, because of compensating changes in other factors of *ER* If we were to contrast the abundance of an insect species in one locality with the numbers of a species having a similar *BP* in a distant locality, we should find that the same underlying relationship existed between abundance and environment That is to say, if in one locality one set of factors were of higher value than in another region, then some other factors would have to be correspondingly lower if the abundance of the two insects were approximately the same This is illustrated by a comparison of the factors of *ER* in tropical and temperate regions In some of the tropical islands, for example, Hawaii, the combined physical and nutritional factors of environmental resistance are of low value Temperature conditions are particularly favorable and at the same time food is available the year around, consequently the insects are not compelled to tide themselves over long periods of adverse conditions In such a climate, biotic factors are much more important and effective than in temperate regions where insects, due to extreme fluctuations of temperature and periodic scarcity of food, meet a much higher physical and nutritional resistance.

A Broken Balance.—If at any time there occurs a change in any set of factors of *ER* without a corresponding change in another set, then the sum total of *ER* will be changed with the result that *C* no longer remains constant and the normal balanced condition in the forest ceases to exist For instance, if the sum total of *ER* is raised, then the sum total of insect abundance will be lowered Were *ER* to be raised sufficiently high, the result would be the complete extermination of the insect We have many extinct species of insects which bear witness to the operation of this force.

On the other hand, if the sum total of *ER* is lowered considerably, then insect abundance may be increased to a point where great damage is done to the forest, and an insect outbreak may

be said to exist For instance, some of the factors that have held a certain insect in check may be so modified that their adverse effect is reduced. Then that particular species, relieved of the pressure that has held it down, becomes very active, gains the supremacy, and dominates its environment

A specific example of this is to be found in what probably took place in the present-day balsam-fir areas of the Northeast, where the spruce budworm became epidemic The chief factor that formerly kept this insect in check was a shortage of food. This limiting factor was gradually eliminated as the original stands of pine, spruce, and fir were replaced by a climax type of nearly pure stands of fir and spruce through the logging off of the more valuable pine or through natural forest succession As a result the numbers of the budworm increased Eventually one or more other factors of environmental resistance were also changed so that they no longer acted with the same force in holding the insect in check This may have been due to either a decrease in predators or the occurrence of weather conditions more favorable to insect development, or possibly to both. There are no records to prove just what changes actually took place but it is known that through a combination of circumstances the sum total of *ER* was reduced. The result was that the spruce budworm came to dominate its environment with tremendously injurious effects

It is possible for adverse weather conditions to disturb the biotic balance not only in the locality where they occur but in localities far removed therefrom For instance unseasonable freezing weather in the spring of the year may result in the starvation of insectivorous birds during their migration, with a consequent reduction in the number of these predators in the regions where they nest This lowering of environmental resistance might conceivably result in an outbreak of a pest in the nesting region

A Restored Balance.—Whenever the balance is broken, nature ultimately brings about a new balance In the case of the spruce budworm, mentioned above, the insect increased in numbers until it finally reached a point where there was an insufficient amount of food to bring the larvæ to maturity As a result almost all the insects starved to death; this ended the outbreak The small remnant of balsam fir and spruce that survived together with other species are forming a nucleus

for a new forest in which spruce and fir will occupy a less prominent place For this reason, the new forest will be a much more stable one than the climax type, and the budworm will occupy a relatively subordinate place therein. Thus a new balance has been brought about by nature but at the expense of a tremendous number of trees.

It is to the advantage of man to see that whenever the biotic balance is broken it be restored as soon as possible in order to avoid economic losses It is even better, when possible to prevent any material disturbance of the original balance Man's part in maintaining the equilibrium will be taken up under Methods of Control and Silvicultural Practices.

DEVICES TO INCREASE ABUNDANCE

It is to the advantage of insects that the balance never be broken unless in their favor Most insect species are provided with devices that help them to increase their actual numbers by reducing the effects of environmental resistance

Insurance of Mating.—We have previously pointed out in our discussion of biotic potential that the sexual type of reproduction is most commonly found among insects and that mating, of the two sexes therefore, is necessary to the survival of most species It has also been shown that insects that reproduce sexually have a lower biotic potential than parthenogenetic species So that in order for the former to keep on any equality with the latter, they require means to overcome the environmental resistance Moreover, the very necessity for mating, demanding as it does the close proximity of the two sexes, means that the physical factor of space may result in raising the value of environmental resistance for a sexual species to a higher value than would be the case with the same conditions of environment acting upon a parthenogenetic species. Consequently, insects reproducing sexually have need of something to offset their relatively low values for biotic potential and high values for environmental resistance.

This they accomplish by means of a number of modifications and adaptations for bringing the sexes together. Many moths are attracted to the opposite sex by odors given off by one sex or the other A glandular structure on the back of the male tree-cricket provides a delectable feast for the female and by its odor attracts her to the male Stridulation among the Orthoptera and

other orders is frequently a means of attracting the opposite sex, and experiments have shown that the flashing of fireflies serves to aid the male in locating the female All these adaptations tend to insure mating with its consequent reproduction of the species.

Care of the Young.—Even after mating, insects continue their fight against the forces of the environment. They have

FIG 31 —A walking stick, *Diapheromera femorata* resting on an oak leaf These insects use no care in selecting a location for their eggs, but drop them wherever they chance to be at the time of oviposition. (*University of Minnesota*)

developed a number of abilities for the protection of their eggs and young by which they offset to a certain extent the destructive forces of environmental resistance Care of the eggs or young by the adults is one of the means by which this is accomplished Care of the young is usually associated with the higher animals, but nevertheless it manifests itself in primitive ways among some insects The highest development of this protective function in insects is usually to be found among the social forms, particularly among the Hymenoptra and the Isoptera, but even among the

solitary species it is sometimes strikingly developed, the solitary bees for example

When an adult insect selects the host tree upon which the larvæ naturally feed and deposits eggs thereon, she is showing a primitive type of care for the young A rather low degree of care for the young is illustrated by Chrysobothris and other buprestids, which deposit their eggs in cracks in the bark of trees or logs of the tree species upon which the larvæ feed In such places, the eggs are inconspicuous and unlikely to be disturbed before they hatch To this degree, parental care is found in most insect species, although there are some insects, like the walking sticks, which drop their eggs without regard to location (Fig 31) Such careless species must, of necessity, have a very high biotic potential if they are to survive, because many of their young will starve before finding suitable food. Such insects are very seldom serious pests

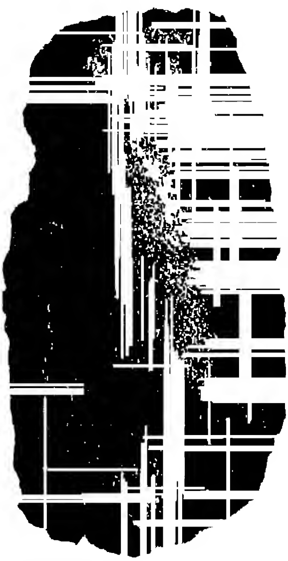


Fig 32 —Egg mass of the gypsy moth, *Porthetria dispar* The individual eggs are hidden by the protective covering (*Entomological Branch, Can Dept Agr*)

Many moths, such as the tussock moths, the gypsy moth, the tent caterpillars, and others, cover their eggs with a protective material. In some cases this only protects the eggs from excessive evaporation but in other instances, particularly where hairs are included in the covering, as is the case with the gypsy moth, it helps to make the eggs unattractive to birds that might otherwise prey upon them (Fig. 32)

One effective device for protecting the welfare of the young is illustrated by some of the Diptera that are larviparous These insects hold their eggs within their bodies until after hatching and deposit larvæ instead of eggs upon their host This is true of many of the Tachinidæ, many of which are parasitic upon the larvæ of forest insects The young of larviparous species have a much better chance of gaining entrance into an active host than do the oviparous flies, because as larvæ they penetrate quickly

into the host and are much less likely to be rubbed off than if they were required to spend some time in the egg stage on the surface of the host's body

Protection by the adult of the larvæ or nymphs beyond the selection of the proper food is rather rare among forest insects with the exception of the social species In most instances, the larva, having been placed near a supply of food, must shift for itself. The mother aphid and the mother tingitid are usually found near their young and are sometimes said to guard their young, but it is open to question whether or not this proximity is an example of parental care More likely it is a question of convenience. In the social species, however, occur many striking instances of a most meticulous care for all the immature stages It is not the mother but definitely designated workers in these social species that usually care for the young The mother, or queen, as she is usually called, attends strictly to oviposition The young of both termites and carpenter ants are cared for in this manner The workers not only feed the young but in the case of the carpenter ant they carry the young from place to place in the nest in an attempt to keep them under as favorable conditions as possible.

Defense.—From the foregoing, it is evident that a primitive type of care for the young is common among forest insects It is also apparent that the degree in which it occurs is not sufficient protection to insure the survival of the species Insects, therefore, must be provided with other means of protection

Some species have, either in the immature or adult stages or in both, disagreeable odors or flavors making them distasteful to predaceous animals that might otherwise feed upon them, and this serves them as a means of defense The Pentotomidæ and other plant bugs, certain beetles, and some butterflies are notable examples of insects possessing this means of defense

Many insects are protected by their inconspicuous coloring or form Few observers of nature have failed to notice how most insects blend into the background on which they rest. Even some of the most gaudily colored species are comparatively inconspicuous in their natural environment. Protective coloring and protective form are so characteristic of insects as to be obvious to the most casual observer

There are, in general, two distinct types of protective appearance In the first type, the color or pattern of the insect's

markings blend into its general environmental surroundings Leaf hoppers, aphids, the carpenter moth, the underwing moths, and many other insects exemplify this protective coloration In the second type the insect resembles in form and color some part of the plant on which it lives, or in some cases it may resemble some other insect that is either distasteful to or feared by insect predators. This last method of protective resemblance is known as mimicry (Gerould, 1916) There are many well-known examples of insect species that resemble parts of the plants upon which they occur, for instance the tree hoppers, the walking sticks, and the spanworms One of our most common examples of mimicry is that of the viceroy butterfly This insect is an almost perfect mimic of the monarch or milkweed butterfly which is said to be very distasteful to birds

FIG 33 —*Chalcophora virginiensis*, one of the buprestid beetles that is protected by its extremely hard exoskeleton

In addition to the various means of defense already mentioned many insects are provided with mechanical contrivances which are of help in protecting them. The hard exoskeleton of the buprestids (Fig. 33) and other beetles makes them much less vulnerable than if their bodies were soft. The sharp spines with which the caterpillars of the brown-tail moth and the tussock moths are armed serve as an effective means of defense against many insect-eating birds. These barbed venomous spines are extremely irritating to the skin of man and those of the brown tail larvæ, by working their way into the skin, cause irritation called the brown-tail rash This is a common trouble among people who are forced to work where these caterpillars are numerous. Other mechanical means of defense may be mentioned, for instance, the strong mandibles of many forest insects These are ready weapons of defense and are frequently used effectively. Another powerful weapon with which some of the Hymenoptera are provided is the venomous sting By means of these various methods of defense, insects are often able partially

at least, to prevent the normal reduction of their numbers resulting from the action of environmental resistance

The Use of Shelter.—Some forest insects are able to evade at least partially the force of environmental resistance by retiring into shelters of various sorts. Shelter protects insects to some degree against changes of weather and also makes them less

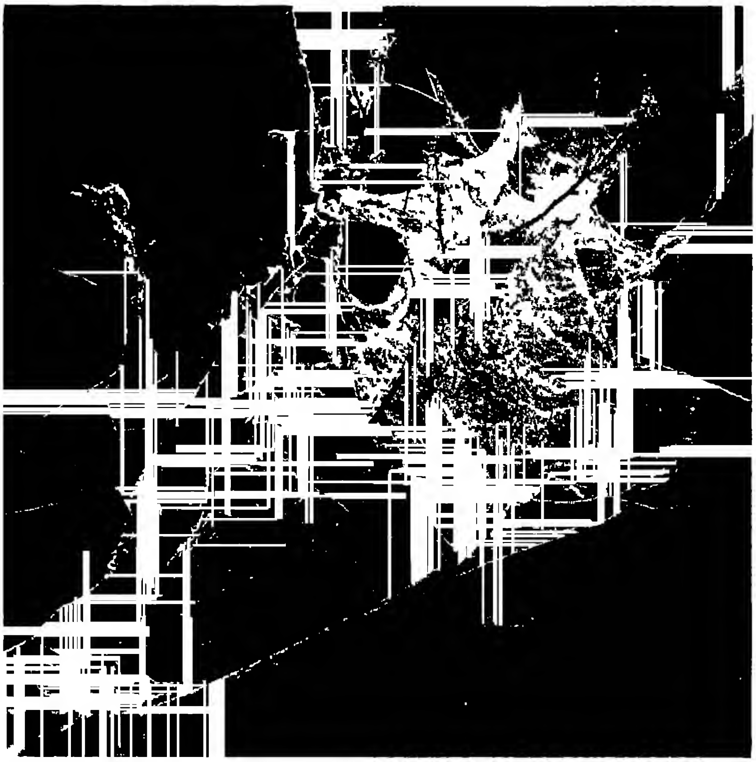


Fig 34 —A nest of the fall webworm into which the insects retire for protection when they are not feeding (*University of Minnesota*)

easily found by their enemies These shelters may be constructed of silk or wax secreted by the insect itself, or of other materials such as sticks, stones, wood or earth, or of combinations of some of these materials.

One type of insect shelter, with which everyone is more or less familiar, is the cocoon By means of this structure, the pupa is protected during its period of quiescence Some insects when

in the larval stage build cases of silk and other materials for their protection throughout the developmental period. The bagworms, for instance, carry a case about with them from the time they hatch until they are fully grown As the larva grows the case is enlarged to accommodate it The female bagworm never leaves the case but lays her eggs and dies therein

FIG 35 —Norway-pine needles heavily infested with pine-leaf scale Each white spot represents a single scale insect covered with its protective shelter (*Bureau of Entomology, U S Dept Agr*)

The spruce budworm and some others of the same group construct another kind of shelter During the larval period they work under a light web of silk that they spin. The tent caterpillars and the fall webworm build nests of silk into which the larvæ retire when not feeding (Fig 34) Other species, like the armored scales and the woolly aphids, are sheltered by their own waxy secretions (Fig. 35).

Some species of insects make use of their food material as shelter Leaf miners are sheltered between the upper and lower cuticula of the leaves in which they feed (Fig 36). Cynipids, gall aphids (Fig. 37), and gall mites find both food and shelter in the abnormal plant growth for which they are responsible. The bark- and wood-boring insects are well sheltered in the tunnels and galleries which they cut.

Certain subcortical species, like Rhagium and Pytho, construct pupal cells of frass and chips beneath the bark where they have been working, thus forming an effective shelter for the pupæ

From these examples it becomes evident that insects have come to make use of many different types of shelter, but all types, whatever their character, aid the insect occupant in overcoming the resistance of its environment.

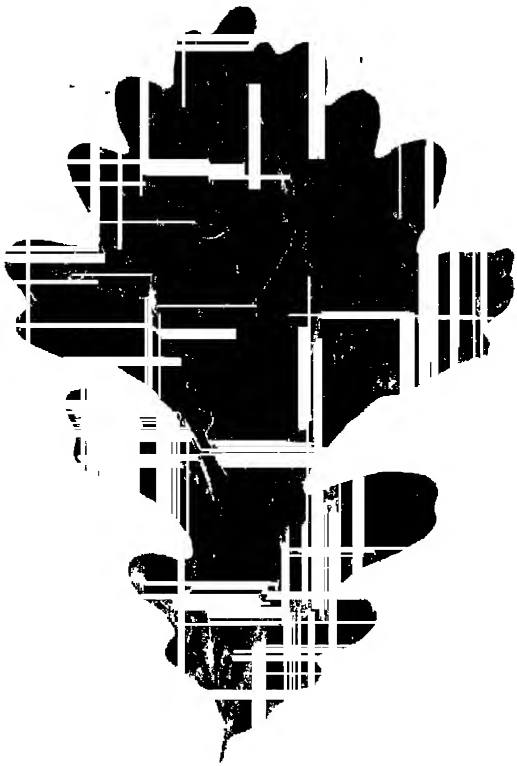


FIG. 36—Blotch mines of Lithocolletes in a burr-oak leaf illustrating how these delicate insects are sheltered between the upper and lower cuticula (*University of Minnesota.*)

Locomotion.—When a predaceous insect or a parasite approaches an insect, or when unfavorable temperatures or unsuitable moisture conditions occur, an insect has two choices. It may remain quiescent, trusting that its enemy will not notice it or that the temperature or moisture conditions will remain within its range of tolerance, or it may try to escape.

Adult insects are, as a rule, well provided with the necessary means of locomotion. Most of them possess both legs and wings

which they are able to use effectively. By means of these appendages they are enabled to escape either from their enemies or from locally unfavorable physical conditions of the environment (Chapman, 1925). Furthermore, the ability to move about easily and quickly helps to bring together the sexes thus insuring successful mating It also helps the insect in its search for food, often makes possible effective distribution, and helps the insect to place its eggs in locations favorable to the larvæ, even though

FIG 37 —Galls sheltering one of the poplar gall-aphids of the genus Pemphigus (*University of Minnesota*)

this may necessitate a considerable amount of moving from place to place.

Larvæ, on the other hand, are generally much less able to move about from place to place None of the immature stages of insects have functional wings with the exception of the may flies which have a subamago winged-stage Larvæ must, therefore, depend primarily upon their legs for their locomotion excep as they are carried from place to place by birds, other animals vehicles, or by wind (Fig. 38). Some of them have well developed legs and can move about rapidly but many others

the caterpillars and grubs for instance, can move only slowly from place to place But even this feeble ability to move makes it possible for many of them to gain more favorable conditions of moisture, or temperature, or to improve their food conditions. This is true of practically all insects that feed upon the surfaces of plants The miners and borers, on the other hand, either cannot move at all, or move with exceeding slowness from one place to another and, therefore, with the exception of some like the carpenter-moth larvæ which move back and forth in their galleries, they must take what comes whether it be good or bad. Such insects, as a result, have a much more limited sphere of

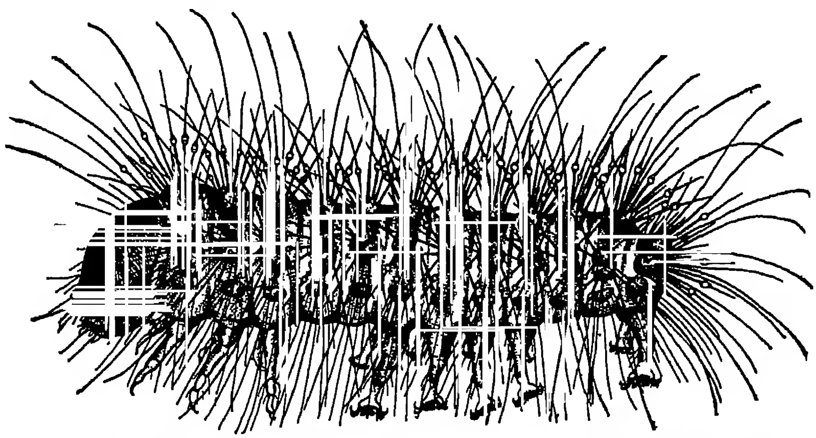


FIG 38 —First instar larva of the gypsy moth showing long clothing-hairs and the so-called "ballooning" hairs These hairs so increase the surface of the insect in proportion to its weight that it can be carried long distances by air currents (*Bureau of Entomology, U S Dept Agr*)

activity; and they are, therefore, confined to those locations where the extremes of environmental conditions always lie within their zone of toleration. The motile species, because they are better able to adjust themselves to changing conditions have a much wider range of activity, and when conditions become unfavorable in one place they move to another

In addition to the use of their legs, many lepidopterous larvæ have another means of locomotion that is useful for protection. These larvæ are able to spin very rapidly a thread of silk on which they can drop out of the way of harm. A larva, having dropped on its thread, can return again later when it is safe to its original position; or small larvæ may parachute for long distances suspended at the end of a free thread. All these

means of locomotion are a distinct aid to the insects in overcoming environmental resistance.

Migration.—At some time during the year almost every species of insect passes through a period of local migration. Migration usually takes place when the insects are in the adult stage, but some species migrate as larvæ. During the period of migration practically every suitable breeding place receives a share of the migrating species. The efficiency of insect distribution can well be illustrated in any large coniferous forest area that has been killed by fire in the spring of the year. Even though the area of killed trees may be one hundred square miles or more, practically every suitable tree will be infested with a share of such borers as Monochamus, Ips, Chrysobothris, certain species of Siricidæ, and other subcortical and xylophagous insects. There could not possibly have been present in the area before the fire sufficient adults to reproduce the multitude of borers found in the area after the fire. It is evident, therefore, that they must have flown in from the surrounding territory The omnipresence of certain leaf eaters in every suitable location is still further proof of the general distribution of at least our common species.

The search for food, or for what usually amounts to almost the same thing—a suitable place for oviposition—is the chief cause of migration; but, apparently, even when food and places for oviposition are abundant, insects may still migrate. Migration is a means by which the intensity of local environmental resistance may be reduced. The value to the species of the ability to migrate is inestimable, because the more widely a species is distributed the less likely it is to be wiped out by some local adversity.

Tropic Responses.—Some insects possess other most interesting characteristics which they are able to use to their advantage in the struggle for existence These abilities relate to the orientation reaction of the insects' body with reference to some physical or chemical effect and are commonly called *tropic responses*. For instance, when one of the hover flies habitually faces into the wind when flying, it is exhibiting a tropic response called *positive anemotropism*. Species which respond positively anemotropically may by the exercise of this response when living near the sea coast prevent themselves from being blown out to sea and thus reduced in numbers

Examples of other types of tropic responses are numerous. In the autumn the ladybird beetles tend to orient themselves when on a vertical surface in such a way that their heads are directed away from the center of the earth. They are then said to be *negatively geotropic*. Under such conditions, if they move at all they will of course climb upward on the surface upon which they are resting. These same insects when seeking a place to hibernate are also *positively thigmotropic*, that is, they respond positively to the sense of touch and, by creeping into cracks, so orient their bodies as to bring them into as close contact as possible with surrounding surfaces. Many insects respond either positively or negatively to chemical stimuli and are then said to be either *positively* or *negatively chemotropic*. Insects that turn toward the light are *positively phototropic*, whereas those that turn away from the light are *negatively phototropic*. Those that seek out sunny places are *positively heliotropic*, whereas those that shun the sun are *negatively heliotropic*.

These terms are descriptive of how insects respond to external stimuli. They do not in any way explain why insects react in certain ways. It must be clearly kept in mind that the terms are descriptive rather than explanatory in order to avoid the common error of trying to explain the cause of certain reactions merely by giving those reactions a name.

Through many generations, natural selection has brought about a survival of those insects which have come to respond in ways that are favorable to the species. Thus it is that tropic responses have had during the course of evolution an important influence in determining how successful an insect will be in overcoming environmental resistance. The insect that orients itself in relation to environmental forces in a way that is most likely to be favorable to it is much more likely to survive than one that is erratic in its reactions or one that fails to react at all. Some authorities think that practically all the activities of insects are the result of tropic responses, but even if this is not entirely true it cannot be doubted that tropisms play an exceedingly important part in the life of insects and that they determine to a large degree whether or not an insect will succeed in the environment in which it finds itself.

The Effect of These Devices.—From the foregoing, it is evident that an insect's abundance depends not only upon the biotic potential of the species and the amount of environmental

resistance but also upon the inherent ability of each insect species to meet and reduce in various ways the force of environmental resistance. Like other inherent qualities, this ability varies with different species It also varies with varying conditions. Under optimum conditions, the ability of insects to overcome environmental resistance is not needed and is, therefore, inoperative. But when pressure is increased so that this ability is needed, its operation becomes more and more important until finally under conditions of extreme environmental pressure it may be so important as to determine whether or not a species may survive Thus, by acting with increasing power as environmental resistance increases and with decreasing power when resistance is reduced, the ability to overcome environmental resistance tends to stabilize insect numbers and to reduce the extreme fluctuations in abundance that might otherwise occur as the result of fluctuations in the environment. In other words this stabilizing force operating in all species helps to maintain the biotic balance

CHAPTER VI

DIRECT CONTROL OF TREE INSECTS

Insect control may be defined as the regulation of insect activities in the interests of man.

The Purpose of Control.—The success of control operations is measured by the degree to which the product or crop protected escapes serious injury by insects. It is generally recognized that it is practically impossible to exterminate any forest pest. The aim of forest insect control is not extermination, therefore, but is to keep the pests within reasonable bounds. It has been shown that outbreaks of forest insects occur as the result of a disturbance of the biotic balance, and that as long as the balance can be maintained outbreaks are impossible. In its simplest terms, the purpose of control is to maintain a balance between pests and hosts.

Of all the influences disturbing the balance the activities of man are the most far reaching and important. The cutting of trees, the building of trails and roads, the construction of buildings, the drainage of land, the damming up of water, all these and in fact practically all of man's activities tend to modify or change environmental conditions and thereby to increase or decrease the probability of insect outbreaks.

In as much as the value of the forest to man depends upon the use he can make of it, it is obvious that it is neither possible nor desirable to attempt to eliminate man's activities in the forest. Effort should be made, however, to carry on these activities in such a way as to disturb the balance as little as possible Furthermore it should be kept in mind that in order to preserve a safe condition in the forest, whenever man, in the course of his activities, removes or reduces the effect of any factor, or factors, he must substitute another force of equal value. This is what we do when we carry on control measures We are merely substituting one set of limiting factors for another set that has been removed

Good illustrations of this point are common in agriculture For instance the colorado potato-beetle originally was kept in

check under natural conditions by food limitations. The individual plants of the native species of Solanum upon which it fed were scattered, and consequently the difficulties and dangers attendant upon finding food were great. As a result, enough beetles were lost so that the number per unit area remained low and approximately stationary from year to year, thereby producing a balanced condition between the beetle and its host When potatoes came to be cultivated as a field crop in the natural range of the beetle, food became so abundant that it ceased to be a limiting factor Under these new conditions the beetles that drifted into potato fields found there that almost any plant upon which they chanced to alight provided suitable food and that the risks connected with hunting for food were much reduced. When the beetle, therefore, became established in cultivated fields, this formerly innocuous species promptly became an important pest not only in its native haunts, but also over wide areas where i was not native It was obviously impossible to grow potatoes in a mixed stand and restore the conditions of food limitation tha originally existed, therefore it was necessary to introduce some other limiting factor. The potato plants are now sprayed with an arsenical to poison the beetle; and, as a result a new balance that is even more favorable to the potato than the condition existing in nature, has been established.

The Cost of Control.—Like every other forest operation, th application of forest insect control must be looked upon from th business point of view It must always be kept in mind tha the material saved by the application of control measures mus justify the expense involved. The cost of control must b materially less than the loss that would have occurred had n protective measures been applied. The lower the value of th trees or wood products to be protected or the smaller the margi of profit, the smaller will be the amount which can justifiably b expended for protection.

With this in mind, the conditions that face the forest entomolo gist will be considered. As a rule the nearer the ultimate prod uct is approached, the more valuable the materials become. I the early years of the forest rotation, the value of the trees is com paratively small. At that time, even small, injudicious expend tures may easily wipe out the entire expected profit. The valu of mature timber justifies greater expenditure for its protectio than does the value of younger trees, the value of partiall

manufactured products justifies a greater expenditure than does standing timber; and in the protection of manufactured wood-products a still greater expenditure is justified

Trees may have very real values in checking soil erosion, or for esthetic purposes. These indirect values must be taken into consideration along with commercial values in planning for their protection. Where trees are used to prevent the erosion of soil

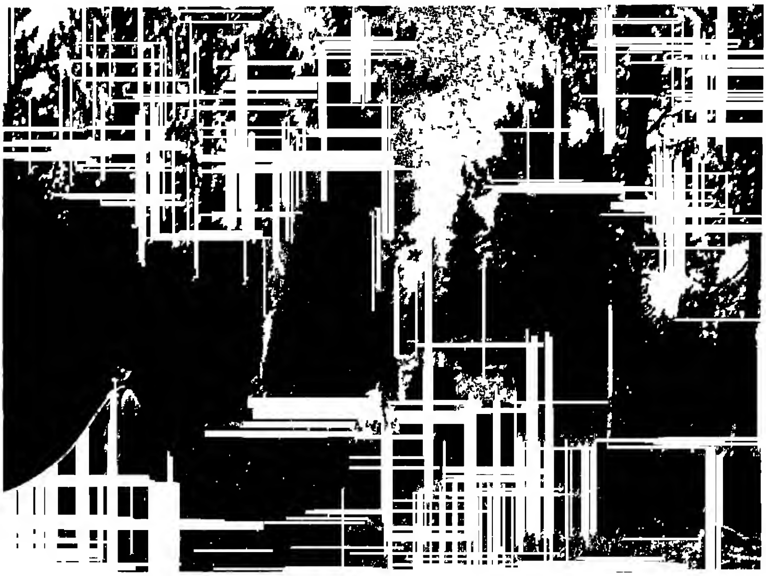


FIG 39 —Spraying lodge-pole pine in Yellowstone Park for the control of defoliating insects The value of a timber forest would not justify such expensive operations as this (*Bureau of Entomology, U. S. Dept Agr.*)

on steep slopes and watersheds, their destruction not only means a loss of a certain amount of wood but, also, may result in damage through erosion of hillsides, and silting of reservoirs, to such a degree that by comparison the loss in wood might appear infinitesimal Under such conditions, larger expenditures for protection are justifiable than in the timber forests. Likewise, park and shade trees have an esthetic value far in excess of their value for wood This value is estimated by some of our best landscape architects and tree surgeons to be $5 per circumference-inch for well placed perfect trees of the best species. Commensurate

appropriations for the protection of such trees may be mac economically (Fig 39).

Thus, the control measure that can effectively and profitabl be used against an insect attacking shade trees may be impract cal under forest conditions because of the excessive expens involved The control measure must, therefore, be suited to th conditions under which it is to be applied, and under each diffe ent condition we may be forced to use a different method c control even for the same insect

On the basis of justifiable cost of control, forest insects may b divided into three major divisions (1) forest pests, (2) shade-tre pests, (3) forest-products pests. Many of the same insects ma be active in each division, but the methods of control will b quite different. The conditions under which they are workin in each case will determine the appropriate methods of contro The real problem of the forest entomologist is to develop not onl ways by which insect ravages may be checked but also methoc that can be applied economically under specific conditions H must continually bear in mind that the control measure h recommends must show a profit from the operation if it is to b justifiable

In this discussion of the control of tree insects various methoc will be discussed, and the general conditions under which eac can be made applicable will be pointed out.

The Classification of Control Measures.—Methods that ca be used for the control of tree insects may be classified into moı or less arbitrary groups as follows:

A *Direct Control*—Operations aimed directly at the insect for the purpo of immediate suppression
- 1 Mechanical methods
  - Collecting, trapping, destroying infested materials, barking destroy broods, heating
- 2 Biotic methods
  - Predators and parasites
- 3 Chemical methods:
  - Dusting, spraying, fumigating, using poisonous bait

B *Indirect Control*—Operations designed to modify environmental facto to secure ultimate limitation of insect numbers
- 1 Chemical and mechanical methods
  - Modifications of food supply, moisture conditions, and tempc ature conditions
- 2 Biotic methods
  - Competition, parasites, predators

DIRECT CONTROL BY MECHANICAL METHODS

As the science of economic entomology has developed, many neans have been devised for the control of insect pests in general Wardle and Buckle, 1923). Until very recently most of these lave been direct methods, and some of them are applicable to he control of tree insects. Many of these direct methods of ontrol have had their origin in Europe but others, spraying, for xample, have been developed to their present high degree of fficiency in America. Wherever they are used, direct methods re generally of a curative nature.

Collecting Insects.—One of the most obvious methods of nsect control is the direct attack upon the pest by collecting and lestroying it during some one of its stages. Such methods are, f course, expensive and can only be used under particularly avorable circumstances Numerous instances where insect utbreaks have been held in check by these means could be cited, lowever, particularly in Europe. Also in some of our American ities shade-tree pests have been controlled in this way; for nstance, in Minneapolis an incipient outbreak of the white-narked tussock-moth was checked through the cooperation of Boy Scouts, and other school children, with the civic authorities n collecting and destroying the egg masses of this defoliator

One of the frequently recommended methods for controlling he white-pine weevil is by collecting the adult weevils in the arly spring during the feeding period that precedes the period of viposition. The beetles are knocked off the pines into a net y jarring the terminal shoots. Such a method may be practi-able where ornamental trees are concerned, but is too expensive o use in forest plantations

Trapping Insects.—Many ingenious devices for trapping insects ave been developed by entomologists The chief of these are by neans of pits or furrows, lights, baits, logs, and bands. The use f trap pits or furrows is commonly recommended in European terature for the capture of insects that spend at least part of heir active life on the ground, but owing to the excessive labor ost it has seldom, if ever, been used in America Trapping by neans of lights has been used to some extent in this country, ut unfortunately it has not proved very successful, because the nsects attracted to lights are largely males, and the few females hat are caught by these devices have in many cases already eposited their eggs Gravid females are seldom attracted in

large numbers to lights Traps baited with some attractive foo material have been somewhat more successful in capturing femal but have been little used except in an experimental way Furth developments in methods of trapping adult insects before the have laid their eggs may provide foresters with an effective mea of insect control.

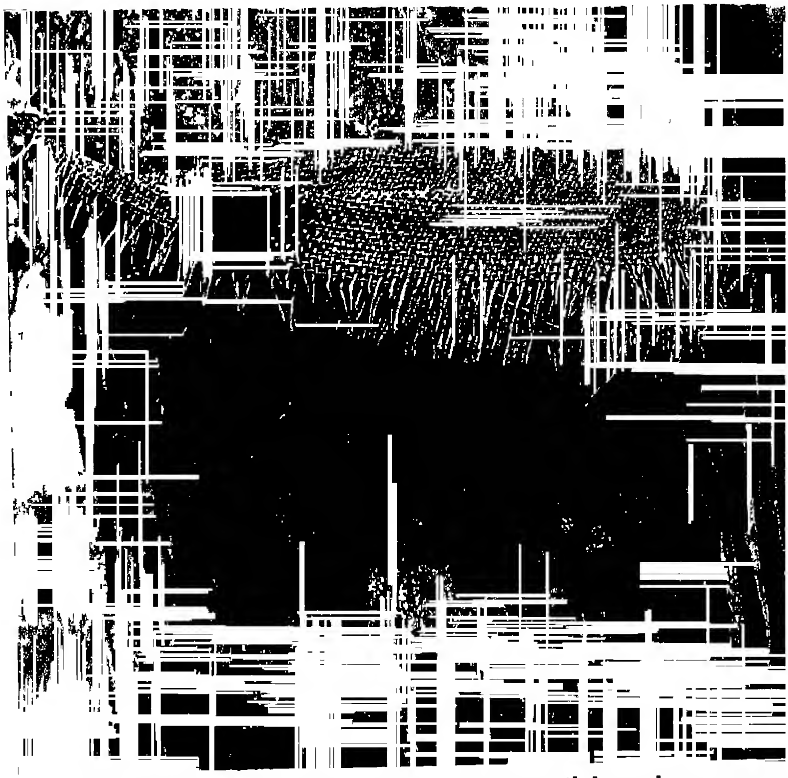


FIG 40.—Burlap band on an oak tree Gypsy-moth larvæ have congreg beneath the band where they can easily be killed. (*Bureau of Entomol U. S. Dept Agr*)

In European forests, trap logs and trap trees intended protect standing timber from the attack of bark beetles sometimes used The principle involved is that certain spec of these beetles prefer freshly cut or girdled trees to heal uninjured trees; as a result, they will deposit their eggs in fres cut logs or girdled trees provided by the forester for this purp Later the broods of beetles in these traps can be destroy

This method has not been much used in America, but it is quite possible that it may eventually find a place in our ultimate plan of insect control.

In the control of certain of our shade-tree pests tending to congregate in secluded places during some portion of the day, the gypsy moth for instance, loose bands of burlap or other material placed around the tree trunks are sometimes used The insects will gather under the protection of the band and can easily be destroyed there in large numbers (Fig. 40) This method is, of course, only applicable on shade trees.

Destroying Infested Materials.—In forest entomological literature one of the most frequent recommendations for the control of bark beetles and wood borers is to cut and burn the infested portion of the tree. Doubtless this is an effective means of control provided that practically all of the infested trees in a community are treated in this way Cutting and destroying the infested portion of trees becomes, consequently, a community control method One insect that might be controlled by this method is the two-lined borer If by community cooperation all dying trees were cut before the beetles emerged an outbreak of this insect could be checked. This method is, however, primarily of use in protecting shade trees and will always have a very limited application under forest conditions.

Barking to Destroy Broods.—In certain cases, notably in the control of Dendroctonus beetles, the barking of cut or standing trees has been employed to destroy broods of these injurious insects Some of these beetles spend their entire life in the cambium region between the bark and wood, while others spend a part of their life in the corky layers of the bark Where the latter type is concerned, the removed bark should be burned or exposed to the direct rays of the sun in order to destroy the insects in the bark Such operations are designed to reduce the numbers of beetles to the point where they cease to be a menace to the surviving trees.

The Application of Heat.—The use of heat to kill wood-boring insects is a comparatively recent development It has been shown that the temperature beneath the bark of logs lying in full sunlight frequently exceeds the fatal temperature of log-inhabiting insects The amount by which the temperature beneath the bark on the upper side of such logs exceeds the temperature of the surrounding air is, other factors being equal,

directly proportional to light intensity (Graham, 1920) (Fi 41). By turning logs every week or two during warm, brig weather it is possible to destroy all insect life in the surface laye of the logs (Craighead, 1920). It was this principle that w applied in the preceding paragraph to destroy bark-beet broods in the bark removed from infested trees For the succes

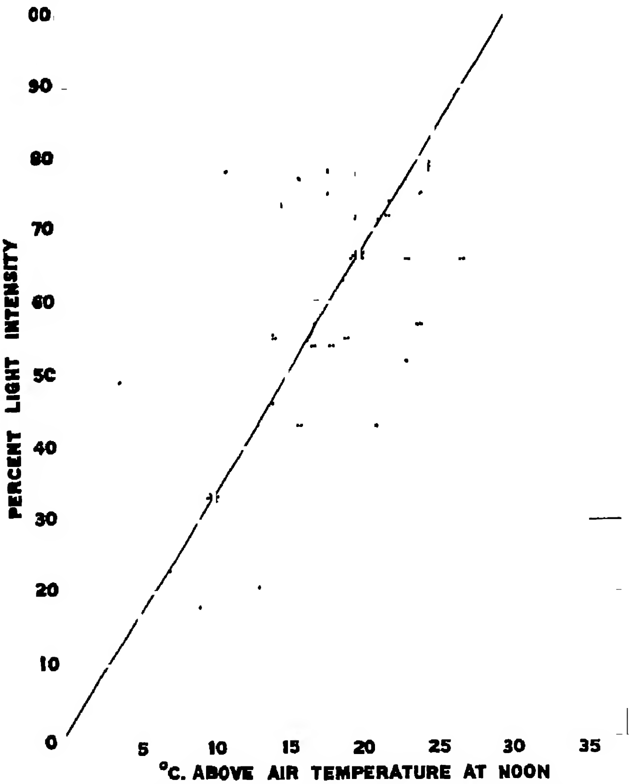


Fig. 41.—Graph illustrating the relation between subcortical temperature a light intensity Each dot represents a daily observation

ful killing of insects it is essential that the material to be treat be exposed to the full force of the sun's rays.

In the process of kiln drying, temperatures in excess of t fatal temperature of wood-boring insects are almost alwa obtained. Even the lowest kiln-seasoning schedule with te perature ranging from 105 to 115° F has proved effective killing certain species (Craighead, 1921) The higher schedu appear to be effective for all wood-inhabiting insects.

DIRECT CONTROL BY BIOTIC METHODS

Although biotic factors in insect control are usually used indirectly, there are some instances where their use is aimed directly at a certain species of insect for the purpose of its immediate suppression. When biotic factors are employed for this purpose they are being used as direct means of control Numerous attempts to apply biotic methods in this way have been made, but most of them have never passed beyond the experimental stage In a few instances, however, these efforts have been attended with more or less success. Some of the successful efforts have been so striking in their results that it is possible we may see a much wider application of this kind of control in the future.

Illustrations.—The most striking example of the successful direct application of biotic methods to the control of an insect pest is to be found in California In the citrus orchards of that state the mealybug, a sucking insect, is one of the most serious pests Since 1918, it has been effectively controlled by the direct use of a predatory beetle, a coccinellid called *Cryptolaemus montrouzieri* According to Smith (1925–1926), the use of this method has passed beyond the experimental stage and has proved itself to be not only very effective but also much cheaper than other possible means of control.

The procedure followed is to rear these predaceous beetles in large numbers and liberate them in the infested orchards in sufficient quantities to destroy the mealybugs before they have caused much damage Special insectaries for the rearing of the beetles are now being operated in strategic locations on the proceeds of the sale of the beetles reared. During the season of 1924, over four million beetles were produced by these laboratories and as a result the mealybugs were effectively controlled over an orchard area of about 20,000 acres. The total cost of this work was approximately $48,750 The beetles were not liberated in every orchard in the infested region but were concentrated in those that were in danger of serious injury. If it is assumed, as Smith does, that one-third of the orchards were actually treated, the cost per treated acre was about $7 29 If, however, the cost is spread over the entire 20,000 acres affected, the cost per acre was only $2 43. When compared to spraying, which costs in the neighborhood of from $25 to $30 per acre for one application, the expense of this method of

control is exceedingly low In 1925, the cost of producing thes beetles was reduced from $12 07 per 1,000 to $8.16 per 1,000, or reduction of approximately 25 per cent.

Previous to the time that this direct method of using Crypto laemus was developed, this predator was effective in certai limited areas in the natural control of mealybugs, but excep in these very limited areas it was not an important influence Now by using it directly, the area in which it is effective has bee tremendously extended

There are no illustrations of the use of parasitic insects fo purposes of direct control, although they have been used t some extent in the indirect way for modifying environmen Neither have we an authentic case of the successful use of fung bacteria, or other parasitic forms to bring about immediate sup pression of a forest insect. One attempt to control a forest pes the larch sawfly, was made by Hewitt in Canada who tried t distribute an entomophagous fungus in forests that were bein injured by this insect. Unfortunately, the attempt was failure.

There is, however, one instance where a fungous disease wa used with apparently successful results against an agricultur pest. In the Central States such a disease was distributed fo the purpose of checking a chinch-bug outbreak and was followe by the destruction of the bugs. It is, however, the consensu of opinion, that this may easily have been a coincidence. Th spread of the disease was apparently made possible by favorabl weather conditions. In as much as the disease was alread present to some extent in the region, the favorable weather tha occurred might have been sufficient in itself without the distribu tion of the inoculum by man to make possible the disease ep demic which destroyed most of the chinch bugs

Obstacles.—The success of fungous and bacterial diseases i reducing insect abundance depends so much upon favorabl weather conditions that the use of these organisms offers com paratively little promise at the present time Other disease not so dependent upon the weather may ultimately be use directly, but at present so little is known about insect disease that little hope can be held out for their immediate use

The success of the use of insect parasites and also of insec predators depends upon the possibility of rearing them on a larg scale at a reasonable cost If it were not for difficulties in th

technique of rearing these organisms we should now be able to use them extensively in direct control.

One of the greatest obstacles to be overcome is the difficulty of providing a sufficient quantity of suitable food to make wholesale rearing possible. This is no easy task. It necessitates either the rearing of large numbers of hosts to furnish food for the parasites or predators that are produced, or the development of some satisfactory artificial food The latter feat has so far never been accomplished although it holds distinct possibilities

In the rearing of the predaceous beetle, Cryptolaemus, in California, the food problem has been solved in a very ingenious way. It was found that the mealybug can be produced in large numbers by feeding them upon potato sprouts By making use of this cheap and easily handled food for producing adequate quantities of the beetle's prey, this predator can be reared at a comparatively small cost. It is easy to see that if it were necessary to rear the mealybugs on citrus trees in order to provide food for the predators that the rearing of the latter would be so expensive as to be prohibitive

Other obstacles in the way of large quantity production of parasites or predators also exist but none of them presents as great a difficulty as the provision of suitable food. For instance, it may be difficult to obtain mating (Jones, 1926) or transportation of the insects to the localities where they are needed may present difficulties. The problem must be solved of synchronizing laboratory production of parasites with the development of the pest in the forest so that a maximum supply of the beneficial species will be on hand at the proper time Until these obstacles are overcome we shall be forced to turn in most cases to other kinds of methods for the direct control of forest pests, and to leave the use of biotic factors to the more indirect phases of control work

CHAPTER VII

DIRECT CONTROL BY CHEMICAL METHODS

In the foregoing chapter it was shown that, with a few exceptions, biotic methods of direct control are not yet developed to a point where they can be generally applied, but that mechanical methods are being used in a number of instances where the cost is not prohibitive We are now ready to consider the most generally used methods of direct-control work, namely, chemical methods

FEASIBILITY OF CHEMICAL METHODS

The use of chemicals for the control of insects has had a phenomenal development since 1868, when paris green was first used against the colorado potato-beetle Since that time insecticides have been improved and perfected to such a degree that chemical warfare against insects has come to be almost universal Until recently, its use in the control of tree insects has been limited to shade and orchard trees Because of the high costs involved in applying insecticides, and because of the inaccessibility of forest lands, this method has in the past found very little use in forests.

The Questions of Cost and Machinery.—Recently, however, the development of poison dusts and of methods for applying these dusts, particularly the use of airplanes for this purpose, has opened up a new field of possibilities in the chemical control of forest defoliators (Fracker and Granovsky, 1928) By using airplanes equipped with a suitable apparatus for distributing the dust it is possible to apply insecticides on forests that would be absolutely inaccessible to any ground machine (Fig 42) The cost of dusting in this way, which is about $3 to $6 per acre, is not excessive in cases where very valuable timber is being protected. It is too high a cost, however, for use under ordinary forest conditions Furthermore, if this method of control were generally practiced on forests, the areas to be covered would be so great that the available supply of arsenicals would be

FIG 42 —Dusting a forest by the use of an airplane to control the hemlock looper, in Peninsula State Park, Wisconsin

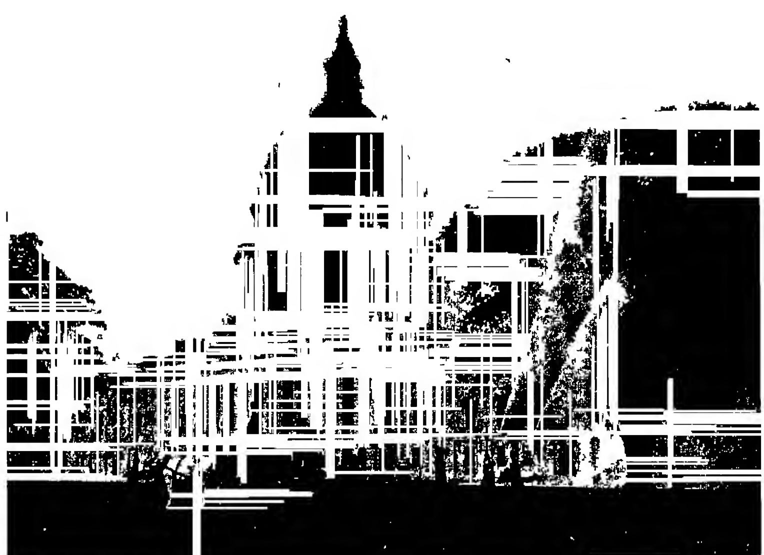


FIG 43 —Spraying to control the elm leaf-beetle on the capitol grounds, Washington, D C Note the height to which the spray is thrown (*Bureau of Entomology, U S Dept Agr*)

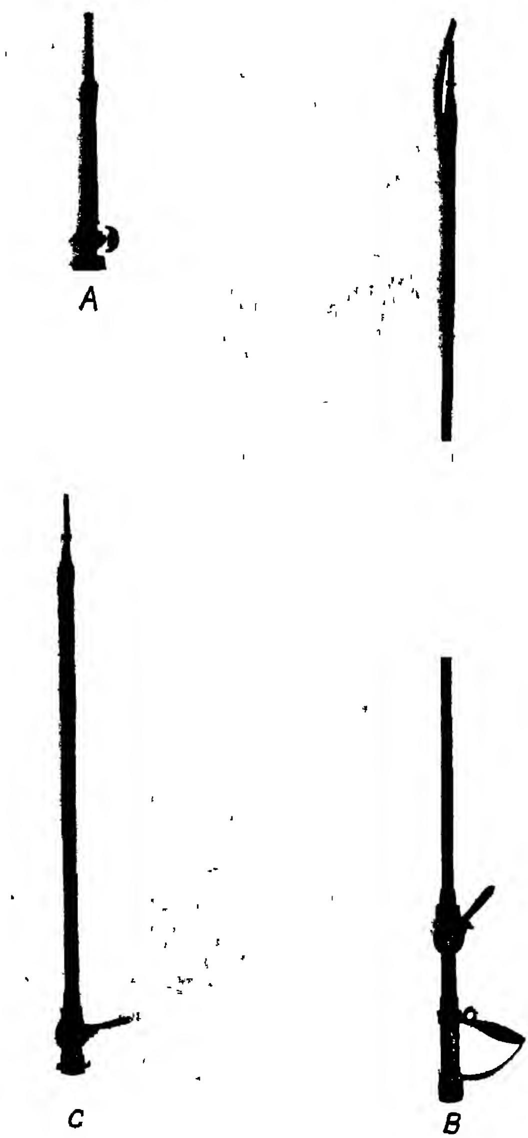


FIG 44—The Worthley nozzle for solid-stream spraying A, old type. B and C, later types By using one of these nozzles with a high pressure it is possible to throw a spray to the top of a tall shade tree (*Bureau of Entomology U S Dept Agr*)

insufficient to meet the demand. This method of control, therefore, will, in all probability, always be confined to comparatively small areas of valuable timber and to the control of spot infestation which, it is feared, may spread and involve extensive forest areas if allowed to go unchecked.

The high-powered liquid sprayer of large capacity has accomplished excellent results in the control of such defoliators as the gypsy moth, when applied to valuable trees in parks, on lawns, and near roads (Kotinsky, 1921). By means of a special nozzle, the spray can be thrown to the top of tall trees (Figs. 43, 44), and by means of long leads of hose, it is possible to work back from the roads to a considerable distance. The cost of spraying is, however, much too high to warrant the use of this method of insect control in the timber forest. It is, nevertheless, and probably always will be, an important method of fighting park- and shade-tree pests. High-powered spraying machinery should be a part of the equipment of every well-organized municipal tree department.

The Effect of Poisons.—But aside from the cost and mechanical feasibility there is another angle to chemical control that should not be overlooked. Even though the economical application of poison to extensive areas proves a practical possibility, little or nothing is known of the effect that the extensive application of a poison would have upon forest life in general. Certainly, the effects of the poison could not be confined to the species for which it is intended. What would be the effect of the application of a poison upon predaceous and parasitic insects, birds, and predacious mammals? Undoubtedly, these would all be affected by the reduction of their food supply that would almost certainly result from the application of poison. It is quite possible that the extensive use of poisons in a forest might easily upset the biotic balance in such a way as to necessitate the continuance of the treatment each year.

In the present state of knowledge, therefore, the application of poisons over extensive areas of forest cannot be generally recommended, even though it may become economically possible. It is a method which should be used with discretion. On shade and ornamental trees, however, conditions are different. Such trees are growing under artificial conditions, and, in such situations, the effect of environmental resistance on insect multiplication is likely to be lower than normal. Hence, it may

be necessary in many instances to supplement the natural forces of biotic resistance by means of poisons For shade and ornamental trees, therefore, the use of insecticides is an important means of protection against insect pests

THE APPLICATION OF INSECTICIDES

Any one of several methods may be used in applying insecticides. The one selected in each instance will depend upon the kind of insect which we desire to control and how it can best be reached

Methods of Application.—Insecticides may be applied in four ways:

1 By dusting with a finely divided poisonous powder

2 By spraying, dipping, or washing with either a finely divided poisonous powder in aqueous suspension, or a poisonous chemical in aqueous solution.

3. By fumigating with a poisonous gas.

4 By means of a poisonous bait

Each of the above methods of application has its place in the scheme of insect control, and each has certain advantages and disadvantages. Dusting is wasteful of materials, but the cost of application is comparatively low. Spraying, when carefully done, and dipping are both economical of materials, but the cost of application in both cases is very high. Fumigation is limited in use to products that can be stored in a tight room or to small, very valuable trees that can be covered by a tent The use of poison baits has received little attention in connection with forest-insect control although they have proved their value in the control of certain agricultural pests, grasshoppers for instance It is possible that further studies of the chemotropic responses of forest pests may open the way for the development of effective baits for certain of them. A wide field of investigation is here awaiting development

Of all the methods of applying insecticides mentioned above, spraying and dusting are in most general use at present. The other methods are little used in the control of tree insects, although some of them may have possibilities of development to the point where they may be even more satisfactory than the two methods in common use at the present time

The Necessity for Even Distribution.—In applying insecticides, by either dusting or spraying, it is essential to success

hat there be an even distribution of the poisonous material n order to accomplish this, it is requisite that the killing naterials be kept thoroughly mixed with the carrier In the process of dusting, if the poison be diluted with some inert ubstance, it should possess approximately the same specific gravity as does the dilutant In liquid spraying, provision nust be made for the thorough and continuous agitation of the iquid to prevent settling Even distribution also necessitates , discharge of either the dust or the spray at a uniform rate. n a liquid spray, the finer the particles of liquid, the better will e the distribution of poison In order to insure a fine spray nd also in order that the spray may be carried to the tops of all trees, a high pressure of from 250 to 500 pounds is necessary n spraying Because of the heavy weight of the large quantities f liquid that are required in applying insecticides in the form f a spray this operation is always carried on from the ground This, of course, calls for expensive equipment. On the other and, the application of dust to tall trees is only possible by the se of airplanes, for no ground machine can blow the dust very igh in the air.

CLASSIFICATION OF INSECTICIDES

Insecticides have been classified, not only on the basis of the nethods of application, but also on the basis of the methods of ntrance into the body of the insect In this latter classification here are two principal groups stomach insecticides and contact nsecticides Frequently, in entomological literature a third roup is recognized. the fumigants. This type of insecticide is o closely allied to the contact type in its action that it will be reated here under that head

Characteristics of Insecticides.—In most respects the two hief types of insecticides differ greatly thus demanding separate iscussion, but there is one characteristic which both types must ossess and another set of characteristics the possession of which highly desirable The essential or requisite characteristic a correct degree of toxicity. In order that any insecticide nay be of practical use it must be sufficiently toxic to kill the nsect pest but at the same time not sufficiently toxic to harm the rees upon which it is applied One illustration of this is found n the use of arsenic White arsenic is highly toxic to insects, ut it is also highly toxic to plants, therefore, in spraying, such

insoluble salts of arsenic as lead arsenate or calcium arsenate which do not injure foliage should be used, even though they are decidedly less toxic to insects than is white arsenic. The proper degree of toxicity is, then, an absolute necessity.

Both contact and stomach insecticides should, in addition, when applied as a liquid spray, possess the powers of wetting, spreading over, and adhering to both the body of the insect and the surface of the plant The efficacy of any insecticide applied by means of spraying depends largely on the degree to which it possesses these important characteristics

Often the distinction between wetting and spreading is not understood The term wetting refers merely to the fact that a physical contact exists between the liquid and the substance wetted. But even though there is a physical contact the liquid may not spread. For instance, when oil and water are placed together there is a physical contact between the surfaces of oil and water, but a drop of water on an oil surface does not spread

If wetting is accomplished, then the powers of a spray to spread will depend upon the forces of cohesion of the liquid, and of adhesion between the liquid and the solid The spreading of a liquid on a solid surface is, therefore, a surface-tension phenomenon. If the force of adhesion is greater than the force of cohesion of the liquid, then the liquid will spread over the surface of the solid If, however, the force of cohesion of the liquid is greater than the force of adhesion between the liquid and solid, then the liquid will collect in droplets In order to be most effective a spray should, therefore, have a comparatively low surface tension so that its force of cohesion will be less than the force of adhesion between it and the surface upon which it is sprayed. The adhesivity of insecticides applied as a dust or as an aqueous suspension depends upon certain physical characteristics which will be discussed later under stomach insecticides

Stomach Insecticides.—Those insecticides that gain entrance into the body of insects by way of the mouth and the digestive tract are called *stomach insecticides* They may be applied in the form of a dust, a spray, or the toxic ingredient in a poisonous bait When used in the form of a dust, or spray, a stomach poison should be a comparatively stable compound that will not decompose on exposure to the air or be dissolved readily by rain It must be capable of sticking to the surface upon which it is applied so that it will remain on the tree long enough to permit the insects

o eat a killing dose. It must also be finely divided so that it ɿay be blown into the air in the form of a cloud or, in case of quid sprays, so that it will be held in suspension in a liquid

Since this type of insecticide must enter the insect's body by ray of the mouth and the digestive tract, it can be used effec- ively only upon those insects that have biting mouth parts, in s much as the sucking type could not ingest a fatal dose of rsenic in the process of puncturing the plant tissues Stomach isecticides are used primarily against defoliating insects, lthough in a few cases they have proved effective in poisoning oung borers as these insects cut their way through the bark 'raighead (1915), for instance, has used successfully a 2 per cent ɔlution of sodium arsenite with kerosene emulsion for this urpose When applied to the bark of freshly cut logs or isceptible trees the young larvæ were killed before they could enetrate into the cambium. Unfortunately, the arsenic, being ɔluble, is easily washed out of the bark by rains; therefore the 'eatment is often only effective for a short time.

The stomach insecticides in most common use are certain 'senicals although some organic substances, like nicotine and ɜllebore, may sometimes also be used. Recent experiments ith silico-fluorides indicate that some of this group of chemicals ıve high insecticidal qualities, they may prove to be both cheap ıd useful substitutes for arsenicals Lead arsenate and calcium 'senate are the two compounds most universally used at present the control of tree defoliators Other common arsenicals 'e paris green, zinc arsenite, magnesium arsenite, and london ırple None of the arsenicals used as insecticides are sold in ı absolutely pure condition All of them contain small quanti- ɜs of other arsenical compounds some of which are water luble Soluble arsenic, because it is able to penetrate and jure leaves to which it is applied, should not be used on trees ven the small quantities contained in some of the insecticides ›ove mentioned are sufficient to cause burning when applied tender leaves The two arsenicals now most commonly used, ıd arsenate and calcium arsenate, contain such small quantities this dangerous substance that their use is attended with very tle danger. The others mentioned above contain larger ıantities of water-soluble arsenic and hence cannot be used discriminately without taking proper precautions By adding ɑe to the suspensions of these chemicals the soluble arsenic

combines with the lime to form calcium arsenate which is, of course, insoluble in water In this way some of the more uncertain arsenicals may be made reasonably safe.

Both lead arsenate and calcium arsenate are usually sold in the form of fine powders that may be applied either as a dust or in aqueous suspension Lead arsenate may also be obtained in paste form. The powdered lead arsenate contains the equivalent of about 30 per cent arsenic oxide and usually less than 1 per cent soluble arsenic Calcium arsenate, on the other hand, contains the equivalent of about 40 or 45 per cent arsenic oxide and is, accordingly, more toxic than lead arsenate In using calcium arsenate there is somewhat more danger of injury to the foliage than with lead arsenate because the calcium arsenate decomposing as a result of a reaction with carbon dioxide in the presence of moisture forms a soluble arsenic. Burning of the foliage may, consequently, result unless there is an excess of lime present. This kind of injury occurs most commonly when damp, foggy weather follows spraying Calcium arsenate has, however, the advantage of being somewhat cheaper than lead arsenate.

Both lead arsenate and calcium arsenate have fairly good adhesive qualities, due in part to the small size of the particles and, in part, to their flake-like structure, but even so, heavy rains are liable to wash off a large proportion of the poison It has been shown that both the surface of the leaf and the particles of these two arsenicals carry a negative electric charge (Moore, 1925). Because opposite charges attract one another, the development of positively charged arsenicals would increase the adhesive power of these materials. Within the last few years a positively charged calcium arsenate has been perfected and is now being sold. In order to increase mechanically the adhesivity of arsenicals, various materials are sometimes added to the spray suspension Some of these are soap, molasses, glue, size, glucose, resin stickers, and gelatine. These materials also increase the spreading power of sprays by reducing the surface tension of the liquid, thus insuring better distribution of the poison.

Contact Insecticides.—Unlike the stomach poisons that have been considered here, the contact insecticides do not need to enter the insect's body by way of the digestive tract They enter either by way of the respiratory system or through the

thinly chitinized intersegmental membranes. In some instances, by means of their action upon the body surface, they may destroy the insect without actually entering the body. In a very few cases they may kill mechanically by plugging the tracheae and thus depriving the insect of oxygen A contact insecticide may gain entrance into an insect's body in the form of either gas or liquid This type of insecticide is useful against small sucking insects, like aphids and scale insects It is also effective against some of the small caterpillars and leaf miners It is difficult to kill the older stages of either the sucking or biting forms because of the greater resistance to poisons that the insect develops as it grows older

The most important factors influencing the action of a contact insecticide are· (1) toxicity; (2) power to wet and spread over an insect's body, (3) low viscosity; (4) the ability to penetrate semipermeable membranes, (5) volatility.

Unless an insecticide kills mechanically by plugging the spiracles, as very few do, it is necessary, as has been already shown, that it be toxic to insects. But the effectiveness of the insecticide is not always in direct ratio to its toxicity Some of the other factors mentioned above are of even greater importance For instance, if a pure aqueous solution of any material is applied to the body of an insect, it will collect in drops and run off. Such a solution, because it would not be able to reach a vital spot, would not be nearly as effective in killing the insect as a much less toxic material that would spread over the insect's body An insecticide that tends to run off the insect's body can kill only by means of its volatile constituents which evaporate into the air, and envelop the insect in a poisonous gas even though the liquid is not in direct contact A liquid that spreads over the insect's body surfaces, on the other hand, will penetrate into the intersegmental areas and, also, will be drawn into the tracheæ by capillarity; thus it will reach those parts where entrance into the insect's body is easiest. Contact insecticides, like stomach insecticides may have this spreading power greatly increased by the addition of soap or some other substance that will reduce the surface tension of the spraying liquid

The viscosity of a solution may in some instances be of importance in limiting the effectiveness of a contact insecticide Viscosity affects not the amount of spreading but the rate of spreading In case of a volatile material, if the viscosity is too

great, the toxic principle may be lost before it reaches a vital spot Also a viscid solution, like strong soap, which increases in viscosity as evaporation progresses, might solidify, as a result of evaporation, before reaching a vital part

Another important factor determining the effectiveness of a contact insecticide is its ability to penetrate semipermeable membranes. This requires either that the material penetrate in the form of gas or that it be in crystalline solution. A non-volatile colloidal solution or a suspension, even though it contained a highly toxic material, would not be an effective contact insecticide because of its inability to penetrate through the membranes into the insect's body

The factor of volatility is also important. The best contact insecticides not only possess the quality of wetting and spreading, but they generally also contain a volatile substance; thus they have two chances of killing. They may penetrate into the insect's tissues in the form of either a liquid or a vapor In the latter case their action is identical with that of a fumigant In some cases, a volatile material, like nicotine, may penetrate the tracheæ in the form of a gas, condense on the walls of the small tracheæ, and then penetrate through the tracheal walls in the form of a liquid In other cases, such a material may enter the tracheæ in the form of a liquid and penetrate the tracheal walls in the form of a gas Volatility also has another important influence A small dose of a very volatile material is not as likely to be fatal as is an equal dose of a less volatile, and equally toxic, substance This is because of the time factor of toxicity In the case of the very volatile substance, evaporation would take place so much more rapidly than in the case of the less volatile substance that a light dose of such a substance is likely to act merely as an anesthetic, whereas, a similar dose of a less volatile, though no more toxic, substance would have remained within the insect's body long enough to have produced death.

There are many different materials used as contact insecticides, in fact, they are so numerous that it will be impossible to mention them all here. Only a few of the most important will be discussed briefly.

The most generally used of all the common contact insecticides are the nicotine preparations. Nicotine is used in the form of a fumigant, a dust, or a spray. It is also used in dips and washes Nicotine fumigation is useful in greenhouses and conservatories.

It is usually accomplished by burning paper impregnated with nicotine. Nicotine dust is made by impregnating some inactive dust, such as hydrated or air-slaked lime, with nicotine. Nicotine dust is used chiefly for a contact insecticide, but it may also have the effect of a stomach poison It is not so effective, however, as lead arsenate. Nicotine solutions for spraying may be made by steeping tobacco leaves in warm water, but the most satisfactory sprays are the commercial extracts These extracts contain a standard quantity of nicotine, usually 40 per cent, and can be easily diluted to the necessary strength.

Commercial solutions are sold in two forms: free nicotine solution and nicotine sulphate solution. The first is volatile and much more toxic than the second. These 40 per cent extracts are usually used at the rate of 1 part of nicotine extract to 800 or 1,000 parts of water. In spraying with these solutions, soap should be added at the rate of 1 pound to 50 gallons to produce spreading When soap is added to a nicotine sulphate solution, the alkali in the soap breaks up the nicotine sulphate and frees the nicotine. Thus, in this case, the soap not only is a spreader but also increases, by a chemical reaction, the toxicity of the spray.

Many mineral oils are effective insecticides, but, because of the great variation in their chemical composition, their use in many cases has been unsatisfactory. The use of kerosene emulsion has been almost discontinued for this reason In comparatively recent years, however, various miscible oils have come into use. These are for the most part standard commercial products giving uniform results. They are proprietary preparations containing mineral oils in combination with a vegetable oil and an alkali to make them miscible in water. They are essentially emulsions These materials are particularly effective against scale insects and insect eggs The fact should be emphasized that, generally, these materials are safe only when used upon trees in the dormant stage.

Soaps containing a high percentage of free alkali have been used for contact insecticides They kill by their caustic action and occasionally by plugging the spiracles of small insects. They are, at best, rather uncertain insecticides

One of the most widely used materials for the control of scale insects and insect eggs on trees is lime sulphur This material is composed of polysulphides which oxidize on exposure to the

air. When a small insect is covered with this material, the rapid oxidation of the chemical robs the insect of its oxygen, this results in a sort of chemical asphixiation Lime sulphur is used also for a fungicide. It is effective against insects only in a solution of stronger concentration than is safe during the season of active tree growth; therefore it can be used to kill insects only when the trees are dormant. Concentrated commercial lime sulphur is available on the market and is the form commonly used Its specific gravity should be about 30° Bé and, when used for the purpose of a dormant spray, should be diluted at the rate of 1 part of the concentrated solution to 9 parts of water Dry lime sulphur and other forms of sulphur and lime are on the market. These substances vary greatly in effectiveness.

Hydrocyanic acid gas is a fumigant which is frequently used in treating infested nursery stock, household insects, and stored grain pests. It is a deadly gas which must be handled with great care The gas is liberated by dropping either potassium or sodium cyanide into a 25 per cent solution of sulphuric acid The cyanide salt is used in strengths varying from ¼ ounce to 1 pound per thousand cubic feet One inhalation of this gas may easily be fatal to man; this material, therefore, should not be used by inexperienced people

From the preceding discussion of direct methods of forest insect control, some conception may be gained of the many means that are at our disposal for checking insect outbreaks The method, or methods, used in any particular instance depends upon the habits of the pest on the one hand, and economic conditions on the other. As has previously been pointed out, these direct methods of control are all curative in character and are chiefly applicable under conditions where the value of the trees, or the wood products, is high The next section will deal with indirect, or preventive, control methods.

CHAPTER VIII

INDIRECT CONTROL OF TREE INSECTS

The control of forest insects by the direct methods previously described is in its very nature expensive. Such methods call for a considerable outlay of capital, time, equipment, and materials. These operations are, as a general rule, curative in character, and are applied after the pest has become sufficiently abundant to be injurious. The indirect type of control that will now be discussed is preventive rather than curative. Under indirect control may be classed all those operations that are designed to modify environmental factors so that conditions become unfavorable for the rapid multiplication of the insects These operations are applied, as a rule, before the insect becomes epidemic. Through a knowledge of the habits and physical requirements of insect pests, injury by them may be prevented, or reduced to the minimum Indirect control may not be such a conspicuous victory for the entomologist from the sensational viewpoint, but it may be quite as effective and even more economical in preventing insect damage.

The application of indirect control calls for a detailed knowledge of the habits of the pests, of their relation to other organisms with which they are associated, and of their reactions to the physical elements of their environment. A much more profound and detailed knowledge of insect pests is necessary for success in indirect control, than for the successful application of direct methods Needless to say, present knowledge is not sufficiently complete to make possible the general application of these indirect methods to all pests, but much progress in this direction has already been made, and at the present time forest entomologists, realizing the possibilities of this line of development, are devoting much effort to the acquisition of the necessary information.

For many years the use of indirect-control measures has had a place in the protection of freshly cut wood Recently, indirect methods have also been applied to the control of insects that

attack the living tree. In the following pages, there will be discussed some of the important indirect methods that have actually been applied to the control of insects of forests and forest products, and some that show promise of development. Indirect control measures may be divided into two groups as follows: (1) chemical and mechanical methods, (2) biotic methods. The first of these will be discussed at length in this chapter, while biotic methods along with silvicultural practices, in which various methods can be used, will be taken up in Chap. IX.

Chemical and mechanical methods of insect control are usually thought of as methods to be used only in a direct way against the insects themselves, but they may be used quite effectively in an indirect way. In most cases when used indirectly, chemical and mechanical methods operate best against pests of forest products, but in some cases green trees may also be protected The object of these methods in all cases, when used indirectly, is to make the environment of an insect less favorable than it would otherwise be; thus, indirectly, through increasing environmental resistance, they would cause an ultimate reduction in the numbers of an injurious species. The environmental factors most commonly modified by these means are the nutritional factors of kind and quantity of food, and the physical factors of moisture and temperature Modification by chemical or mechanical methods of each of these factors in turn will now be discussed

CONTROL BY MODIFICATION OF FOOD SUPPLY

For control purposes, the food supply of an insect may be modified in three different ways: It may be made inaccessible by erecting either chemical or mechanical barriers, it may be made less available by reducing its actual quantity; or it may be made unavailable by changing its composition. The indirect control of insects by the modification of food supply will be discussed under these three headings.

Inaccessibility through Barriers.—Although the use of chemical barriers in the control of wood and tree insects has not been developed to a very high degree of efficiency, it has been demonstrated that many of the common spray materials may be used in this way. A number of them have a decided repellant effect upon insects, examples of these are bordeaux mixture, lime sulphur, iron sulphate, and even whitewash All of these repel

insects for a time after they have been applied. In addition to these materials, there are a number of tree paints on the market that are intended to give protection from insect attack Most of these, however, are valueless, and some are actually injurious. In general, the use of these paints should be avoided. One very good repellant wash has been developed by Pettit (1923) This is a soft-soap mixture containing naphthalene that is effective against a number of borers, Chrysobothris, for example Its use is limited, however, because of its drawbacks: it is difficult to mix and apply; it is rather expensive, and it must be applied several times during a season to insure satisfactory results Still other chemicals, for example, creosote and carbolineum, applied in the form of emulsions, have a strong repellant effect upon many wood borers In some instances they have been used successfully on green trees (Graham, 1916).

The use of chemical repellants on freshly cut wood has not been practiced commercially, but experiments, by Craighead (1922) have demonstrated that logs can be protected in this way He found that spraying or dipping logs in creosote diluted with kerosene would prevent all insect attack Ordinarily this material is too expensive for use on logs intended for lumber, but it may be profitably used in protecting rustic work, and possibly in the protection of exceedingly valuable logs intended for special uses He also found a mixture of pyradine and kerosene, in the proportions of 1 to 10, to be highly effective for a repellant when applied to green logs Snyder (1924) has demonstrated that creosote is an effective repellant against termites.

In the protection of trees from insect attack, mechanical barriers are sometimes used. In Europe they have even found a place in timber forests, but in America their use is confined to shade and other ornamental trees, in as much as economic conditions will not permit the application of these comparatively expensive means of insect control on trees intended for lumber

The use of sticky bands to prevent defoliating insects from reaching the foliage by climbing trees has proved so effective that it is widely used in the control of cankerworms, tussock moths, and gypsy the moth on shade trees. Such bands can only be effective against insects that reach the foliage by crawling up the tree trunks The commercial preparation called "tree tanglefoot" is the most convenient material for this purpose,

as it can be purchased ready for use in any quantity desired The Gypsy Moth Laboratory of the U S Department of Agriculture has developed a very effective banding material which is being used almost entirely in the gypsy-moth work whenever

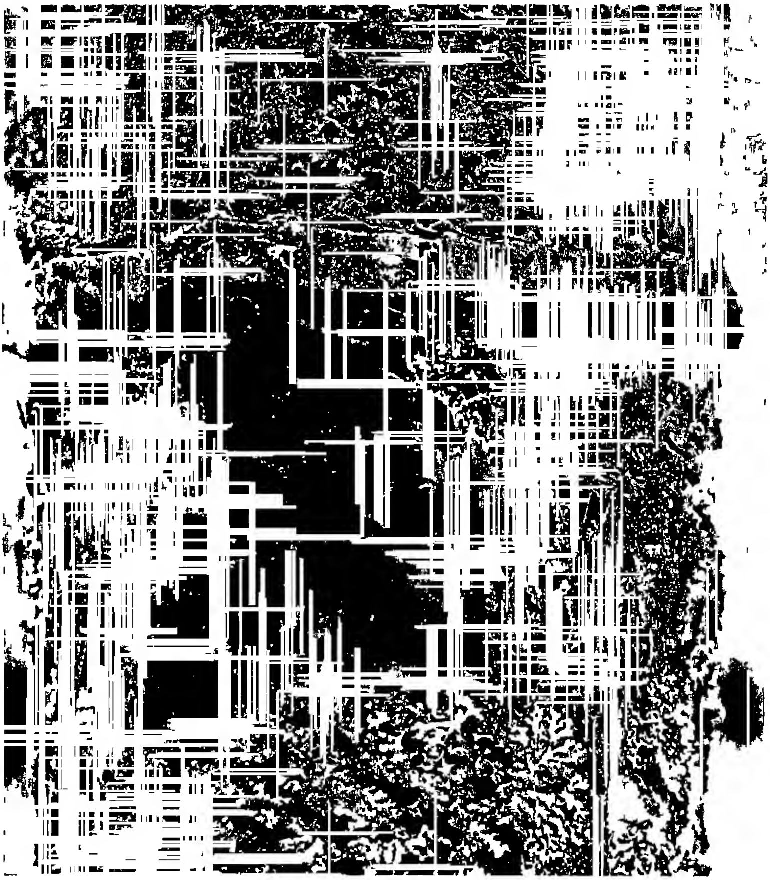


FIG. 45.—Gypsy-moth larvae congregated on a tree trunk below a sticky band over which they are unable to crawl (*Bureau of Entomology, U. S. Dept. Agr*)

banding is done (Collins, 1920). To be effective the bands should be watched closely to insure renewal whenever they lose their sticky quality (Fig 45) The screening of the trunks of especially valuable shade trees has been recommended by Burke (1921) to prevent their reinfestation by the carpenter

moth. That is, of course, a method too expensive to use except under unusual circumstances

In the protection of forest products, particularly seasoned materials, the use of mechanical barriers is important. For instance, one of the most effective barriers against insect infestation is a coat of paint or varnish applied over the surface of susceptible wood. This is particularly effective against dry wood insects, for example, the lyctus powder-post beetles (Snyder, 1926) Because these beetles deposit their eggs in the open pores of seasoned hardwood lumber, a coat of paint or varnish, that closes these pores, prevents infestation.

Reduction in the Quantity of Food.—Reduction in the quantity of food available for insect pests offers an effective means of insect control, especially in the protection of forest products. This may be accomplished in several different ways. Three of the most usual are by prompt utilization, by barking freshly cut logs, and by the disposal of waste materials.

The prompt utilization of logs and other forest products is one of the most obvious methods of preventing insect injury to this class of materials, but it is surprising how often the importance of this simple means of protection is overlooked A tree is most susceptible to insect attack just after it has been cut or killed. As the cambium region and sap wood dry out, the wood becomes less and less attractive to a large proportion of wood-inhabiting insects The greatest amount of insect damage is done during the first season after the tree has been cut or has died After that, the organisms causing decay hold the center of the stage.

For this reason, one of the most effective ways of preventing insect injury, and likewise the succeeding fungous injury, is to utilize the logs as soon as possible after they are cut; or to salvage without delay trees killed by fire, insects, or other causes before they have deteriorated. This calls for prompt action in many instances.

In the case of trees killed by a spring fire, the problem of prompt utilization is almost hopeless because the trees will be infested with borers within a few weeks after they are burned. Unless it is possible to divert logging operations to the salvage work immediately, heavy losses cannot be avoided When the trees are killed in the summer or fall, on the other hand, they will not be seriously injured until the following spring In the

latter instance, there is more time to plan and execute salvage operations, the mere cutting of the killed trees, however, does not mean that there will be no loss Logging is only the first step in the process of salvage. If losses are to be avoided, the logs should either be sawed immediately or be treated by one of the methods discussed hereafter. This is particularly true of fire-killed material because of the great attraction that scorched timber appears to have for wood borers. The same rule also applies to green logs cut in the regular logging operations The shorter the time between felling and manufacturing, the smaller will be the chance of loss as the result of insect attack

By removing the bark from freshly cut logs infestation of this kind of material by wood-boring insects may be prevented, to a considerable degree This is because many species of wood-boring insects that injure freshly cut wood, for example the pine sawyers, other Cerambycidæ, and many Buprestidæ, require, during the early larval period, the succulent tissues of the inner bark and cambium The young larvæ of these species work in this region where the protein content is high, and where the available food materials are easily digested and assimilated. Later in their development, many of them tunnel into the solid wood, where they do their greatest damage. Because of the unfavorable conditions for borer development, the eggs of these insects are usually not deposited on healthy living trees, therefore, the wood when cut is usually uninfested The removal of bark from freshly cut logs, pulpwood, or other wood products, destroys the source of food for the early stages of these pests, and thus makes impossible their infestation of the logs

Barking, although not as cheap as water treatment, as shown later, is not an expensive operation. The average cost in the Lake States is about 10 cents per log This amount would be correspondingly higher, per log, in the larger timber of the Northwest, but would be lower on the basis of cost per thousand feet Nevertheless, even though the absolute cost is not excessive it is not justifiable under all conditions The advisability of barking depends upon the cost of labor, the size, and the value of the logs. Without doubt it pays to bark butt logs and second cuts that are to be held over the summer, because the grade of these logs might easily be reduced from a select grade or number 1 common to number 4 common, thus causing a loss of from $50 to $100 per thousand board feet. On the other hand, it is

doubtful whether or not barking small, knotty logs or top logs will ever be profitable, because such logs contain only low-grade materials, with the result that the reduction of grade by insect attack would be comparatively slight. The profitable application of barking, therefore, depends primarily upon the value of the protected material

By properly disposing of waste materials in which injurious insects may breed, many of our insect troubles may be prevented. For instance, in manufacturing plants that use hardwoods, the

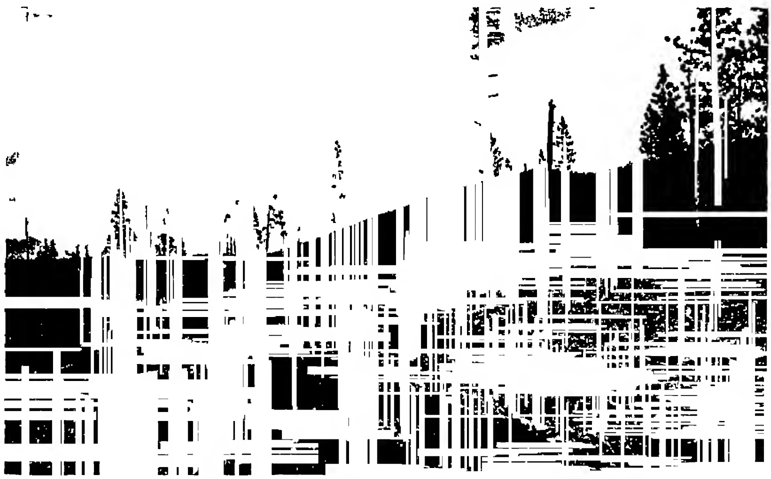


FIG 46—Large pieces of slash left after a slash-burning operation that was regarded as being very thorough In the usual operation much more would be left Breeding places for most of the potentially injurious insects that live in slash have not been destroyed (*Bureau of Entomology, U S. Dept Agr*)

danger of powder-post-beetle infestation will be greatly reduced if all waste wood is promptly disposed of The accumulation of such waste is very likely to lead to insect troubles sooner or later.

Likewise, in the forest, the proper handling of logging waste or slash is sometimes important from the standpoint of insect control The ordinary methods of slash disposal are directed primarily toward fire prevention, and as a result, only the smaller and more inflammable portions of the slash are taken care of (Fig 46) This type of disposal has little or no influence upon dangerous forest pests, because the potentially injurious species either do not breed in logging waste at all, or else they are found only in the larger parts like the large branches, broken logs, and

stumps (Graham, 1922) In order to be effective in checking the multiplication of potentially injurious insects, disposal of the larger parts by utilization, barking, burning, or some other suitable method is necessary.

The general consensus of opinion is that hardwood slash is almost never a breeding place for insects that attack living trees, and even coniferous slash is not such a serious menace as it has sometimes been regarded. There are instances, however, when coniferous slash presents important problems (Keen, 1927) As long as logging is going on, and fresh slash is continually being supplied by successive operations, the insects breeding in this material will find adequate feeding places for each generation. When logging operations end in a locality, then the slash insects, because of a scarcity of readily available food, may attack and kill standing trees or injure advance growth Such outbreaks are usually sporadic and seldom occasion great injury.

One of the important insects that appears to be definitely associated with eastern white-pine slash is the pales weevil, *Hylobius pales* (Pierson, 1921) This insect breeds in green pine stumps and injures advance growth by feeding on the bark of these small trees. The barking of stumps, in regions where this pest is abundant during the mid-summer following logging, has been recommended to check its rate of multiplication, with protective results for the seedling trees on the cutover areas

Changes in Food Composition.—The composition of an insect's food is generally very definitely limited Each species or group of species has its own special food requirements In view of this, whenever it is possible, to so change the character of an insect's food that it is no longer suitable for its use then another valuable means of insect control presents itself. Fortunately, this is often possible, and consequently some of the most effective control methods are based on the changing of food composition. These methods are especially applicable to the control of cambium and cambium-wood insects working in freshly cut wood The cambium region, even at best, is suitable for the development of these insects for only a comparatively short time. If this period can be still further shortened, so that there is not time for the development of the insects, or if a change in composition can be brought about before the wood is exposed to insect attack, injury by cambium-wood insects can be materially reduced or even eliminated

One of the ways by which wood may be protected from the ttack of cambium insects is to give an opportunity for changes o take place in the cambium before time for the insects to begin ork. This can be accomplished by cutting at the proper time f the year Unpublished results of experiments by Craighead, nd also by other workers, show decided differences in suscepti-ility to insect attack between logs cut at different seasons of he year. This condition is particularly true in the northern egions, where there is a long period of dormancy during the inter

Experiments at Itasca Park, Minn , have shown that logs cut uring late summer and early autumn are more immune to orer injury than are logs cut at other seasons of the year. Such gs are not immediately attacked, because no cambium insects re flying at that season. Not until the following spring, 8 or 9 onths after cutting, will these insects be on the wing. By at time, changes will have taken place in the cambium which educe its attractiveness and desirability for use as a breeding lace Exactly what the changes are, that occur during the utumn and winter, is not known, although they are evidently oth physical and chemical in nature. They are frequently ccompanied by a change in the color of the tissues, although ometimes little apparent change occurs. When the cambium anges color it apparently no longer furnishes suitable food r the cambium borers, but even when no apparent change has ccurred, wood cut in the autumn is not so susceptible to the tack of these insects as wood of the same tree species cut in te winter or early spring

Cutting at the most favorable time is one method of insect ontrol that has been little developed. In view of the results experiments, it appears possible that, in some instances, a onus might profitably be paid by buyers for material cut in te summer, to encourage small operators to increase the aterial cut at that season of the year, thereby reducing the uantity of wood susceptible to insect attack.

When it is impracticable to cut wood at such a time that it ill no longer contain palatable food by the time the insects fly, may be possible to change food conditions by rapid seasoning as to shorten the period of susceptibility. With thick-barked eces this may be accomplished by barking. This accomplishes double effect. It reduces the total quantity of food available

for the cambium eaters, and makes possible the rapid drying of the sapwood, with the consequent food changes that soon makes the wood unsusceptible to the attack of the insects which feed in green sapwood With thin-barked pieces to accomplish rapid seasoning, all that is necessary, in many cases, is to pile the wood in well-ventilated piles. This latter method is not certain in the cooler northern latitudes, however, because of a slower rate of drying. In such localities, both barking and piling in well-ventilated piles are necessary to insure rapid seasoning.

In the South, on the other hand, rapid seasoning for the purpose of modifying the character of the food, by means of sun curing of logs, has been used successfully Under this method the pieces of wood are either piled in open piles or, in the case of logs, placed side by side on skids. In the latter case, it is necessary to rotate the logs every few days to insure even curing on all sides

Seasoning wood for the purpose of producing unfavorable food conditions for insects is not only applicable to logs and bolts, but also has its place in the protection of sawed lumber. During the process of drying, food modifications occur which prevent all future attacks of some insects, even though moisture conditions may later become favorable Ambrosia beetles are representatives of this group. The more rapid the seasoning, the shorter will be the period during which attack by these pests will be possible Careful piling of green lumber in such manner that there is free circulation of air through and around the piles hastens drying, but where the equipment is available, kiln drying is an even better course of procedure

Still another means of protecting freshly cut wood from insect attack is by water treatment. The chief effect of this treatment is to change, unfavorably, the moisture conditions. This effect will be discussed in the following section. But water treatment also changes food conditions. It is a matter of general knowledge that after logs have been in water for some time they cease to provide suitable food for many wood-boring species. Logs driven in water to the mill are only slightly susceptible to insect infestation when removed from the water (Fig 47). Deadheads when taken out of the water are practically safe from insect attack. Craighead, in some unpublished work, has shown that a submergence of 12 months so changes the physical and chemical

nature of logs that they are no longer susceptible to infestation. Short periods of floating in water have comparatively little effect upon food composition within the wood. For this reason, short periods of driving followed by removal from the water have little or no effect either upon the insects present in the logs or upon the susceptibility of the wood to later infestation. To be

FIG 47.—Driving logs down the Big Fork River, Minnesota. These logs will be in water for from several months to a year. They will then, on removal from the water, be immediately sawed into lumber. There will, therefore, be no opportunity for insect injury to them

effective in changing food conditions, water treatment must be continued over a period of from several months to a year.

CONTROL BY MODIFICATION OF MOISTURE CONDITIONS

It was shown in Chap. IV that one of the most important factors determining the rate of insect development is moisture Insect development is limited by the moisture requirements of each species to a definite moisture zone Outside this zone of moisture toleration, development is impossible, consequently, effective control of insects in logs may be accomplished either by lowering the moisture content of the logs below the limits of the insect's zone of moisture toleration or by raising the moisture content above that zone

Reduction of Moisture.—We have seen in the preceding section that piling, barking, and sun curing are methods which may be

used to change unfavorably the composition of insect's food We shall now see that these same methods may be used for the purpose of reducing the moisture content to a point below the zone of moisture toleration. The piling of freshly cut wood in well-ventilated piles has frequently been advised in the belief that it was all that was needed to produce adequately dry conditions to inhibit the development of most insects (Fig 48) As a matter of fact, it has been found that only logs with very thin bark will season quickly and even these, unless exposed to high

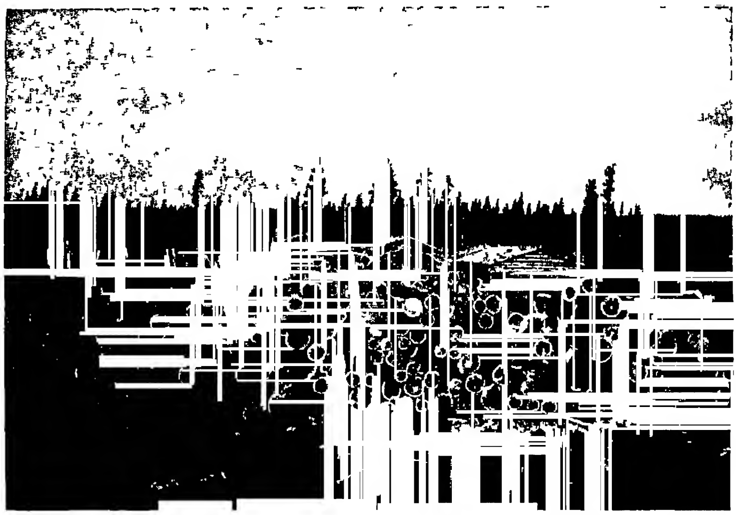


FIG 48 —A pile of logs, left in the woods over the summer, heavily infested with wood-boring insects (*L W Orr*)

temperatures in a dry atmosphere, will retain a rather high moisture content for several months. In most cases, therefore, comparatively rapid seasoning of freshly cut wood cannot be obtained except by removing the bark previous to piling Even when this is done, the rate of drying is frequently so low that the period during which the wood is sufficiently moist to allow insect development is too long; consequently injury is sustained (Fig. 49).

If truly rapid drying can be secured, it is an effective means of control, for it operates in two directions at the same time Indirectly, it prevents future attack by wood-boring species and, at the same time, it directly checks the activities of insects

that have already become established in the wood, slowing up their rate of development and sometimes even stopping it entirely. An example of this is found in the ease by which the larvæ of the balsam-fir sawyer, *Monochamus marmarator*, are killed by thorough drying of the wood in which they are working. This effect has been observed by the author in attempts to rear this insect Unless the logs are kept moist few, if any, of the beetles will emerge

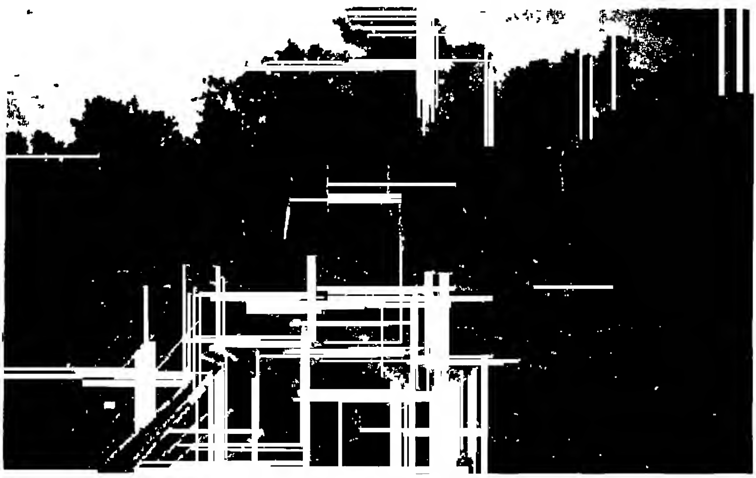


FIG 49 —Pulpwood piled on dry ground awaiting shipment by boat This wood will be heavily infested by wood borers (*L. W. Orr*)

Increase in Moisture.—In many instances it is much easier to raise the water content of freshly cut wood above the point of insect toleration than to lower it below the favorable zone We have already seen how water treatment, like seasoning, may control insects by changing the composition of their food. Now we shall see that this same treatment, with certain limitations, may be used most effectively to change the moisture content to such an unfavorable condition that insect development will be checked and sometimes stopped entirely.

There are two different ways of using water treatment. One is by sprinkling the wood with water, the other by floating it in a pond The method selected for any particular case will depend upon existing conditions Each has its advantages and disadvantages

The sprinkler system has been limited in its use to pulp wood, although it could be used with equal effect upon saw logs Under this system, during the season of insect activity, the wood throughout the pile is kept continually dripping wet by throwing water on the piles. This may be accomplished by means of an overhead system of pipes, or the water can be thrown on the piles from the ground by means of either stationary water guns or a hose. The overhead system is expensive to construct and may interfere with the handling of wood in the yard, but it is very cheap to operate because it requires a minimum of attention. The method of throwing water onto the wood from the ground requires little or no additional equipment, in as much as most wood yards are equipped with water mains for fire-protection purposes; but it requires a certain amount of labor in directing the stream of water. In both methods of using the sprinkler system it is, of course, necessary to provide a system of drainage to carry off the surplus water that runs from the piles of wood

In treating wood by the sprinkler system, it should be continually borne in mind that the effectiveness of the operation depends primarily upon the thoroughness of the wetting. Unless all the wood in the pile is kept continually wet, the treatment will have little or no beneficial effect. This system is likely to give the best results when applied to irregularly piled wood of short length. On evenly stacked piles the water is likely to run off rather than to drip through the pile

The second method of raising the water content of freshly cut wood above the point of insect toleration is, as stated above, by floating it in water. This method can be used to protect not only wood stored at the mill but also freshly cut material in the woods. There is no more economical way of preventing injury to wood that must be held over in the forest during a season or more than to get it into water

If the wood is free from infestation when it is floated, no infestation will take place. If it has been infested by wood borers prior to floating, the borers will develop no further and, if the wood remains in the water long enough, the insect inhabitants will ultimately be killed by the effect of excessive moisture (Fig 50)

The chief objections to the floating method of protection are (1) The obvious fact that frequently adequate water space may not be available (2) A considerable proportion of the floated

wood will become water-logged and will sink, thus necessitating either taking a loss or being faced with a heavy salvage charge.

In connection with this discussion of water treatment other benefits than the protection of freshly cut wood against insect injury should not be ignored Wood treated by either sprinkling or floating is protected not only against insects but also against the growth of fungi. Both staining and decay are checked or prevented by water treatment Another benefit of water treatment is the reduced fire hazzard It is practically impossible to burn wood stored under either of the methods discussed. The

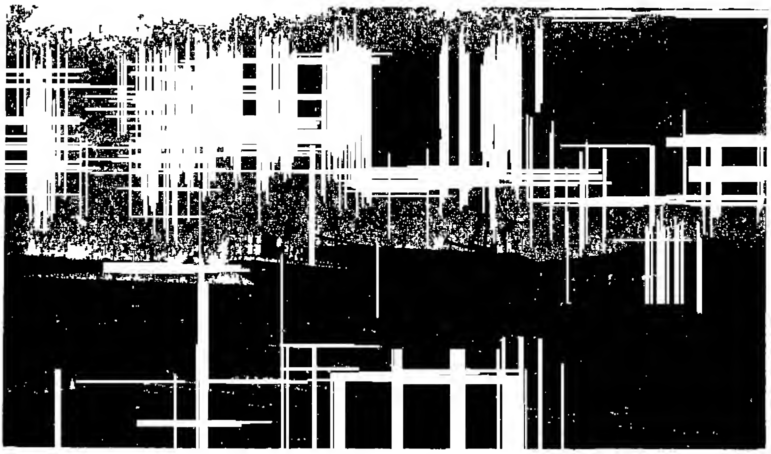


FIG 50—Pulpwood stored in water at Grand Marais, Minn This wood will not be attacked by insects (*L W Orr*)

danger of fire in and around the mills using one of these systems is, therefore, reduced, with the result that insurance rates are lower than under conditions where risk of fire in the wood yard is an important consideration. All these benefits of water treatment combine to make it an especially valuable means of protecting wood

CONTROL BY MODIFICATION OF TEMPERATURE

Wood-boring insects have, as was stated in Chap IV, a definite zone of temperature in which they are active Within this zone the rate of development varies with the temperature The higher the temperature, the more rapid their development.

Likewise the lower the temperature, the slower their rate of development. This reaction to temperature provides us with another useful weapon in insect control. We can raise the temperature of wood above that favorable for insect development, or we can reduce it until it is below the favorable zone. In either case, the activities of the insect inhabitants will be checked.

Reduction of Temperature.—In cool climates where, even at best, there is little more than enough heat for the successful development of insects, their control in wood is sometimes possible by operations that will still further lower temperature or which will reduce the heating effects of the sun during periods when the weather is warm. The simplest way by which this effect may be obtained is to protect the wood from the effects of the sun by shading. In warm, humid climates, of course, the control of insects by reduction of temperature is not ordinarily feasible The smaller the surplus amount of heat, the easier it will be to check insect development by reducing temperature.

Comparatively recent experiments in Minnesota have shown that the temperature of logs can be very much reduced by heavy shading, and that the rate of development of certain wood borers is correspondingly retarded, or even stopped entirely (Graham, 1925). The pine sawyer, which under favorable conditions completes its development in one year, requires from two to four years in heavily shaded logs Chrysobothris is even more seriously affected and is unable to exist under heavy shade Heavy shading also appears to reduce the amount of infestation of logs by wood borers to some degree To obtain satisfactory results, however, very heavy shading is necessary Slight shade has a tendency to make conditions even more favorable for wood-boring insects than full sunlight and frequently results in an increased rate of infestation. Thus, when shade is used to reduce the damage to logs, caused by wood borers, it is essential that it be very heavy.

In the Lake States, experiments have shown that the principle of heavy shading may be used effectively in preventing the multiplication of those slash insects which are potentially pests of living trees. By piling the smaller slash over the larger parts, physical conditions in these larger parts become unfavorable for the development of the potentially injurious insects that might otherwise find favorable conditions there

Increase in Temperature.—The control of insects by increasing temperature has a much wider possible application in direct than in indirect control, but the indirect effects are not inconsiderable. Even under conditions where the temperature does not become sufficiently high to kill the insects within the logs, intense insolation may be sufficient to prevent oviposition by most species For this reason solar treatment may have both a direct and an indirect effect

CHAPTER IX

OTHER INDIRECT CONTROL MEASURES

As seen in the foregoing chapter, insect numbers may be limited, by chemical and mechanical methods, through modification of some of the nutritional and physical factors of the insects' environment It is also possible, in some cases, further to increase environmental resistance by increasing the value of the biotic factors This phase of control work will be discussed under Indirect Biotic Methods This leaves only one of the groups of factors entering into environmental resistance unused by man in his attempt to prevent the too rapid increase in insect numbers The time is soon coming when even these little-known physiological factors are going to be the basis for protective control work by the forester The possible use to which he may put these characteristics of trees will be discussed under the general heading of Silvicultural Practices

INDIRECT BIOTIC METHODS

The discussion of biotic balance in Chap V shows that in tropical climates biotic factors are of greater importance than in temperate regions in maintaining the balance. This condition probably explains the emphasis that entomologists working in the tropics place upon the importance of biotic methods of control. In the more rigorous temperate climates there has been a tendency to depend less upon biotic methods It was seen in Chap VI that there are very definite limitations, at the present time, on the possible use of biotic factors in direct or curative control work. In the realm of indirect control, it should be possible to accomplish a great deal in the prevention of outbreaks of forest pests, by manipulation of the biotic factors of the environment. In some cases, this may necessitate the introduction of new parasites or predators, more often it will mean various activities for increasing the numbers and effectiveness of some parasite or predator already present in the forest In either case, of course, the object is not, as in direct control, the

immediate suppression of an insect pest, but aims rather to increase the value of the biotic factors of environmental resistance for the purpose of ultimate limitation of the insect's numbers. Since so little, aside from the introduction of a few beneficial species, has actually been done in this field of control, our attention will be centered, chiefly, on some of the underlying principles which should serve as a guide in the future use of indirect biotic methods.

The Use of Competition.—The first of the biotic factors, competition, has seldom if ever been consciously used by man to control insects. We should, nevertheless, not overlook the use of this factor, which has distinct possibilities, as a means of insect control. In fact, it is even now in operation, although without conscious direction on man's part. Workers in the Bureau of Entomology have, in a number of instances, noted the checking of bark-beetle outbreaks as a result of competition between bark beetles and cerambycid borers. These borers breed in the trees infested by the bark beetles and, by feeding upon the green tissues of the cambium region, rob the bark beetles of their food. When the cerambycids are abundant, the bark-beetle broods may be almost entirely destroyed.

It is possible that competition, such as that just referred to, may explain why we seldom have outbreaks of injurious bark beetles in regions where continuous logging is being carried on. The cerambycids breed freely in logging waste and, where there is an abundance of this material, it is known that these beetles are much more numerous than in other places. Since this is true, it is logical to assume, even without recorded quantitative evidence, that competition between the borers and bark beetles is keener where slash is abundant year after year than it is under other conditions. It is possible, therefore, that, where logging is continuous, bark beetles may be controlled by competition with the cerambycids.

It is easy to see that when means of handling this kind of competition are found, we shall have at our command a biotic method of preventing abnormal insect abundance. Even now, though we are yet unable to direct or control this force, we can take care, in cases where this type of competition is occurring, to avoid activities that will interfere with its beneficial influence.

Control by Parasites.—The second biotic factor of the environment is parasites. The use of parasites in indirect control work offers great possibilities for future use. In order to obtain wholly

satisfactory results in the use of parasites in indirect control work, it would be necessary to possess a detailed knowledge of the habits and ecological relationships of these organisms. Although our knowledge is still far from complete, it is nevertheless sufficient to permit the laying down of some principles determining the effectiveness of these factors in control. It is also sufficient to warn us of some of the dangers attendant upon their use.

The effectiveness of a parasite in controlling insect pests depends upon several characteristics, the first of which is the possession of a high biotic potential. Any insect possessing this ability will be able to take full advantage of a reduction in the sum total of environmental resistance resulting from an increase in host numbers. Other things being equal, the higher the biotic potential of the beneficial species, the more effective will it be in keeping its host or hosts in check In this connection, it is well to note that those parasites among which polyembryony occurs, many of the small Hymemoptera for instance, have a decided advantage over other parasites in the production of numbers Such parasites are capable of tremendous control possibilities, even though each individual parasite is able to parasitize comparatively few hosts.

A second characteristic that determines the effectiveness of a parasite is the accurate synchronization of its life history with that of its host. As a rule a parasite can attack only one stage of the host; in order to be effective, therefore, it must be ready to oviposit at a time when that stage of the host insect is available. A specific parasite, one that is limited to a single host should have the same length of life cycle as its host, or a series of brief generations during the period of host availability. It might, otherwise, be ready to oviposit at a time when the host was not at a suitable stage. In order that a perfect synchronization between parasite and host may be maintained, it is necessary that the rate of development of the parasite either be stimulated or be retarded by the same factors that stimulate or retard the host's developmental velocity. The effect of these factors must be practically identical upon both host and parasite, or else they must both have a well-established seasonal periodicity that is synchronized.

Although a high biotic potential and an accurate synchronization with the host species are the characteristics of primary importance

in determining the effectiveness of a parasite, there are also other characteristics that should not be disregarded. For instance, a general parasite that is synchronized with a certain pest may be more effective in controlling that pest than would be a specific parasite equally well synchronized. This is particularly true during the period following the decline of an outbreak, because at such a time the general parasite, owing to its ability to attack a variety of host species, would not suffer so greatly from a food shortage as would the specific parasite Under such conditions,

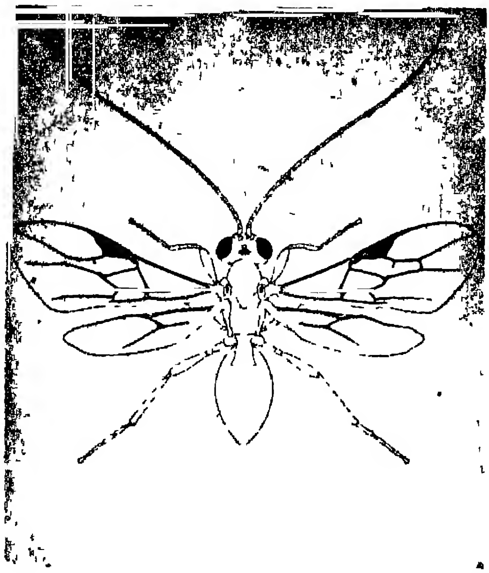


FIG 51 —*Opius fletcheri* adult female (*Bureau of Entomology, U S Dept Agr*)

the specific parasite would be reduced in the same proportion as its host, whereas, the general parasite would be much less reduced because it could transfer its activities to other hosts. The general parasite would then be in a better position to retard the subsequent multiplication of the host than would the specific parasite

Many parasites have several generations during a single season. In such cases, if their most abundant host is not available at all times, alternate hosts will be required This necessity may reduce the value of the parasite because its ability to multiply is of necessity limited by the number of its least abundant host

Another characteristic that frequently determines a parasite's effectiveness is its ability to compete successfully with other

species. When two species of parasite are brought into direct competition, the stronger will survive The survivor may or may not be the most effective in controlling the host species. When we introduce parasites into a new region for the purpose of controlling a pest, therefore, it is always advisable to know their ecological relationships before introducing species that may be competitors. The importance of competition between parasites is illustrated by the experience of the scientific workers of the Bureau of Entomology, U. S. Department of Agriculture, in Hawaii, in connection with the control of the Mediterranean fruit fly (Pemberton and Willard, 1918). After this fly became established in Hawaii, a parasite belonging to the genus Opius was introduced (Fig 51). This parasite became established and was parasitizing 60 per cent or more of the fruit-fly larvæ Later another parasite from a different part of the world was introduced. According to laboratory tests this second parasite, a member of the genus Dyachasma (Fig 52), was able to find and parasitize 40 per cent of the fruit fly. It was thought that the introduction of this second species would increase the percentage of parasitization above the amount possible with Opius alone; consequently it was liberated on the island When Dyachasma became established, the total percentage of parasitization was reduced rather than increased. It appears that Opius parasitized the 60 per cent of the fruit fly most easily reached, and Dyachasma parasitized the 40 per cent most easily reached. The 40 per cent least accessible remained unparasitized. Thus, the 40 per cent most accessible were parasitized by both species. If the supply of food in a single fruit-fly larva had been sufficient to support both parasites, or if Opius had been the stronger, there would have been no change in the percentage of flies parasitized It happened, however, that when double parasitism occurred, the Dyachasma larva was able to complete its development but Opius was not Thus, 40 per cent of the fly larvæ were killed by Dyachasma and, incidentally, two-thirds of the Opius larvæ were killed at the same time As a result, with each generation, the number of Opius was reduced until in 1921 less than 10

FIG. 52 —*Diachasma tryoni* ovipositing into a fruit-fly larva working in a fruit (*Bureau of Entomology, U. S, Dept Agr*)

ent of the fruit-fly larvæ in Indian almond fruits were itized by Opius, whereas over 35 per cent were parasitized)yachasma (Willard and Bissell, 1926). Dyachasma has he ability to increase its rate of parasitism above 40 per hence in this case, because of the inability of the more ive parasite to compete successfully with its less effective etitor, the introduction of a parasite actually reduced the iveness of parasites in controlling a pest.

ll another characteristic that determines the effectiveness arasite is its ability to reach and parasitize its prey. Little ılty in this respect is presented by the insects that are l on the exposed surfaces of trees, but those that bore into ssues of trees present a much more difficult problem. Many e parasitic Hymenoptera are well fitted to parasitize these n larvæ. Some of them are provided with long ovipositors ı they are able to insert through solid wood, and there ıt their eggs in or on the larvæ working therein The larger es can reach a larva an inch or even more beneath the ce The smaller parasites of this group cannot penetrate eply because their ovipositors are not so long. For this n, they must confine their attention to borers that are near ırface.

studies of the pine tipmoth, it has been found (Graham Baumhofer, 1927) that the percentage of parasitism is r among the larvæ of that insect mining in the tips of jack han among those mining in western yellow pine. Perhaps lifference is due to the comparative size of jack-pine and v-pine tips. The jack-pine tips are much more slender than ıose of yellow pine It seems quite natural that a larger ırtion of the tipmoth larvæ working in these slender tips be reached by the small parasites that attack them than l be possible in the thicker tips of yellow pine If this is then the introduction of a parasite larger than any now nt, but still small enough to complete its development in a ıth larva, might conceivably result in an increased per- ge of parasitism.

e requirements for an effective parasite may be summed up 'ew words it should have a high biotic potential; it should 'nchronized with its host in such a way that the adult ıtes are flying during the time when the susceptible stage e host is available, it should be able to feed upon more than

one species of host; it should not be restricted in its multiplication by the necessity of spending an alternate generation in a host that does not occur abundantly; it should be able to compete successfully with other parasites when double parasitism occurs, finally, it should be able to reach and parasitize a large proportion of the potential hosts All of these requirements should be borne in mind in the use of parasites for the control of insects

At the present time, the principal use of parasites in the indirect control of insects in America is the introduction of exotic species. This work is being conducted, for the most part, by representatives of the Bureau of Entomology, U. S Department of Agriculture In most instances, the insects against which the work is directed are agricultural or horticultural pests that have been introduced accidentally into this country from other parts of the world. Some of these are the alfalfa weevil, the European corn-borer, the Mexican bean-beetle, the Japanese beetle, and the brown-tail moth. Only one forest pest, the introduced gypsy moth, has received a great deal of attention. About $50,000 is spent annually in the collection in foreign lands, in investigation, and in colonization of parasites of the gypsy moth and its associated horticultural pest, the brown-tail moth.

This work has now been carried on for a period of over 20 years, with the result that some 60 species of foreign parasites of these insects have been introduced. Of these, about 16 species have become established in this country and are now helping to control the insects. Seven or eight of these have become abundant and promise to be important Just how effective they will ultimately prove to be remains to be seen, but it is not likely that they will become any more effective than they are in Europe, where occasional outbreaks of the gypsy moth occur in spite of the presence of its parasites. But even though the parasites do not come up to the expectations of some enthusiasts, they will certainly bring about an increased environmental resistance that will be helpful in reducing the frequency and severity of gypsy-moth outbreaks.

In the work of introducing parasites, an attempt has been made to bring in every primary parasite that has any promise of being effective (Burgess, 1926), on the theory that the more of these enemies present the greater the probability that one or more of them will be ready at any time to check an increase of

he moth. The chief basis for this theory is the fact that no one pecies of parasite controls the moth in any part of its native ange. Furthermore, in different localities different parasites re important.

This theory is quite logical in so far as it applies to parasites hat are supplementary in their action, but, when the multiplication of species leads to the introduction of competing species, t is probable that the combined effect of several parasites may e less than the effect of a single major parasite, a condition that ve have seen illustrated in Hawaii. In view of this, the introluction of all possible primary parasites is certainly dangerous, ecause it is almost certain that in this process the introduction f competing species cannot be avoided; and once the undesirble ones are established they cannot be eliminated, thus misakes in introduction can never be corrected

In view of the dangers attendant upon the introduction of arasites, the greatest caution should be used in this work Care should be exercised to avoid the introduction of parasitic pecies that may be hyperparasites, that is, those that parasitize ther parasites This calls for a detailed knowledge of the abits of these insects The introduction of species that will ompete directly with species already present must be avoided, nless it is certain that the new species will be more effective han any of those already established Care should be used to elect for introduction those parasites that promise to be the nost effective and the best suited to the environment in which hey are to be placed The selection can only be made with afety after careful ecological studies have been made of the arasites, the hosts, and the environment.

The introduction of parasites has been used primarily in onnection with the control of introduced pests, but it is possible hat species may be found that will be an aid in checking the rate f multiplication of some of the native pests as well The way n which the tachinid parasite *Compsilura concinnata*, introduced s a parasite of the gypsy moth, is now attacking more than 90 ative species is an indication of some of the possibilities that hould not be overlooked (Howard, 1922).

When introduced parasites once become thoroughly acclinated and established, they take their place in the new nvironment where, like any native species, they serve as a atural check for pests The effectiveness of both native and

introduced species can be increased, to a certain extent, by certain methods of silvicultural practice These will be discussed later in this chapter.

Control by Predators.—The part that predators play in environmental resistance has been previously discussed Although no one doubts the value of this group in maintaining a check on insect numbers, the use of predators in supervised control work has received entirely too little attention In fact, in actual forest practice in America, comparatively little consideration is given at present to these important control agencies. This condition must be changed if we are to take advantage of all the possible means of preventing the ravages of forest insects.

Predators have been used indirectly in several instances with successful results. Examples of this are the introduction into New England of the fiery hunter, *Calosoma sycophanta*, which aided in the control of the gypsy moth, *Porthetria dispar*, and the introduction and establishment of certain Coccinellidæ, the vadalia beetle, for instance, in the California citrus region, with great success in the control of scale insects Because these predators are better suited for the work of control than any of our native species, they are a valuable addition to our fauna The fiery hunter, for instance, although it is a carabid or ground beetle, is unlike any of our native species in habit. The larvæ of this insect, instead of staying on the ground like its relatives are able to climb trees in search of their prey (Fig 53) Because of this ability, the fiery hunter is able to feed upon arboreal caterpillars, and is very useful not only in helping to hold down the numbers of the imported gypsy moth, but also helps to check the multiplication of native caterpillars.

The introduction of predators is attended with somewhat more evident risk than is the introduction of parasites, because of the greater flexibility of habit and the greater powers of mobility characteristic of predators in general We have a number of examples that should make us cautious in introducing predators without carefully studying the situation beforehand The English sparrow, for instance, was introduced to control certain hairy caterpillars, and has become a pest in certain parts of the country. The mongoose in some of the West Indian Islands (Williams, 1918) has destroyed the snakes that it was introduced to destroy, but now it is making poultry raising in these islands

impossible. Nevertheless if predators are selected only after careful consideration, the dangers attendant upon their introduction may be minimized.

Before man can make full use of predators as an instrument to check insect pests, much data must be collected regarding the relations existing between predators and the rest of the environment.

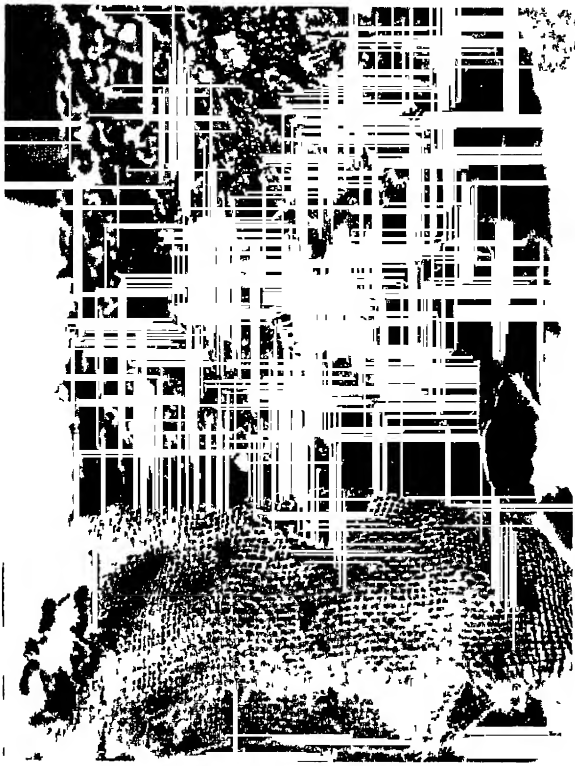


FIG 53 —A burlap band placed around a tree to attract the congregating gypsy moth larvæ to a point where they can be killed Larvæ of the fiery hunter are feeding upon the gypsy moth caterpillars. (*Bureau of Entomology, U. S. Dept Agr*)

ment. In the meantime, the least he can do is to see that, in so far as is possible, no silvicultural methods are put in practice which will tend to reduce the numbers of beneficial predators already present in any environment. Anything he can do along silvicultural lines to make conditions favorable for their natural increase will be just that much gained. The possibilities existing along these lines will appear in the following section.

SILVICULTURAL PRACTICES

It has already been seen that the control of insects by mechanical or chemical methods has limited possibilities of application This is in part due to the expensive character of these operations and in part to the inaccessibility of many forest areas. With the application of more intensive methods, the latter of these difficulties will be largely removed, but it is doubtful if even then chemical or physical methods of insect control can be applied to extensive forest areas. It has also been seen that the biotic factors of the environment offer decidedly favorable possibilities as indirect means of combating insect pests of the forest, but that these have not been developed sufficiently to accomplish the results for which they have been striving. Whenever possible the breaking of the biotic balance must be prevented, so that control measures for its restoration will not be required. This work of aiding in the preservation of a balanced condition can best be brought about by silvicultural practices.

It has long been recognized by foresters that a forest growing under natural conditions is less subject to insect attack than is one where natural conditions have been disturbed. This means that a forest in which the various environmental factors have come into a state of equilibrium is safer than a forest in any other condition. Here is the fundamental keynote for silvicultural practices which will make the use of ordinary control measures largely unnecessary. If trees are grown under such conditions that the biotic balance is maintained throughout the rotation, there will be no need to resort to costly measures to restore a broken balance

This is not so simple as it may first appear to be The factors that react to produce the conditions of balance do not always have the same values at every stage in the development of a forest. As the trees grow and crowd out first the grass and weeds, then the underbrush, and later certain trees, the food factor varies in both quality and quantity. Also as the trees develop, the physical conditions within the forest vary, and the animal life of the forest is modified accordingly But throughout this developmental period, during which the environmental factors are continually changing in value and in their relation to one another, because the variations are compensating the balance between biotic potential and environmental resistance will normally be maintained. If this were not true, it is evident that

forest could never reach maturity because it would certainly ıeet with some calamıty ın the form of a pest before many years f the rotatıon had elapsed. The aım of the forester, therefore, ıould be to develop methods of sılvicultural practıce that wıll ıaintaın the bıotıc balance. If he ıs successful ın thıs effort hıs rest wıll not suffer from ınsect outbreaks

To accomplısh this end, ıt ıs necessary to have an accurate nowledge of the environmental factors involved At present, ıe knowledge of these factors ıs decıdedly lımıted, and ıt wıll be ıany years before they can be handled wıth precisıon. In ıte of thıs ıgnorance ıt is not necessary to despaır for there is a lan that has already proved ıtself to be successful ın the virgın rests Thıs plan is the one followed ın the development of the ırgın forest as ıt orıgınally occurred ın each forest regıon, type, ıd sıte Later the accumulatıon of data wıll probably make ossıble the development of modıficatıons of nature's plan that ıll better answer the requirements, but for the present ıt should e attempted, as nearly as possıble, to pattern the forests of the ıture on those that have proved themselves successful ın the ast.

Regulation of Forest Composition.—Too often, even in regions here mıxed natural forests are the rule, foresters have made the ıstake of concentratıng theır efforts in the establıshment of a ngle specıes of tree over large areas. Such an effort ıs doomed, ventually, to faılure, unless ıt is economıcally possıble to subıtute for the force of envıronmental resıstance, lost by the ıange of forest composıtıon, an equal force ın the form of ntrol measures The sad plıght of the Saxon forests, once the ıde of European forestry, illustrates well the ultımate fate of e artıficıal pure forests As a result of the nun-moth outbreaks companıed by other unfavorable condıtıons these forests of ıre spruce are at present ın a desperate condıtıon.

Only those specıes of trees that normally grow ın pure stands n be handled safely ın pure stands. Many of the two- or ree-leaved pines, for example, western yellow pıne and jack ne, are rarely found ın anythıng but pure stands. In such ses, a condıtıon of balance has been establıshed between the ees, the ground cover, and the pests. In these natural pure rests, therefore, ıt ıs just as necessary to preserve thıs balance protectıng the entıre floral composıtıon, ıncludıng trees, rbs, and shrubs, as ıt ıs to preserve the orıgınal composıtıon

of the mixed forest Overgrazing either by wild or domest animals, ground fires, the introduction of exotic game anima in fact, any force that will result in a modification of the grou cover in natural pure stands, should be guarded against a general principle. Either overgrazing or ground fires may reduce the variety of the flora, and thereby the total number phytophagous insects in a region, that insectivorous predatc will not be able to find sufficient food at certain seasons of t year; their numbers will consequently be reduced, with the resı that some one insect upon which they normally feed at anoth season may be able to multiply in such great numbers as to serious damage to the forest.

It should be recognized, in the long run, that in nature forces combine to prevent the favoring of one species at t expense of others. Whenever, by some combination of c cumstances, one species does come to dominate an environme as is the case in the climax-type pure forest, nature usua sooner or later brings about a reduction of such a species. T is often accomplished by an insect outbreak; thus, outbrea may arise as a result of the action of natural forces without t interference of man. In the managed forest, it should ultimat be possible to prevent such outbreaks and, eventually, to prodı a forest that will be safer from insect outbreaks than even t natural forest.

The disastrous results rising from failure to regulate for composition may be found many times in the annals of for entomology. Perhaps one of the best examples of this is to found in the spruce-budworm outbreaks that devasted the spru balsam stands of eastern United States and Canada between 1! and 1920 A detailed discussion of this insect will be taken later, but a few of the salient features may well be introduced this point. All the available evidence appears to prove that t great series of outbreaks, which destroyed over 200,000,000 co of balsam fir and many million cords of spruce timber, arose a result of the type of forest developed in the infested region b combination of unregulated, or improperly regulated, cutt operations and forest fires. These two agencies producec forest that contained a very high percentage of balsam fir, most suitable food tree of the spruce budworm (Fig. 54) T change reduced the environmental resistance by improving f conditions and, probably, by decreasing the natural enemies

the budworm to a point where rapid multiplication of the pest was possible. Regulation of forest composition is the obvious way by which this insect may economically be kept from overabundance.

Another illustration of the effect of forest composition upon the susceptibility of trees to insect attack is to be found in the jack-pine situation in the Lake States. This species of tree was originally confined to the very poor, sandy lands where other

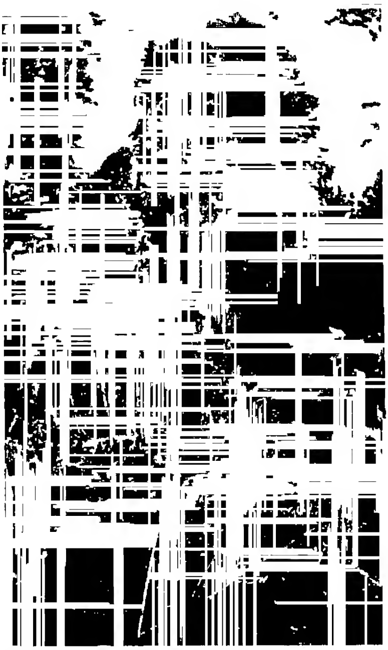


FIG 54 —A forest of balsam fir that has been practically destroyed by the spruce budworm. (*L. W. Orr*)

species of pine could not grow. Although the tree occurred normally in pure or nearly pure stands, this type was broken up into comparatively small areas by other forest types. After the virgin stands of white and norway pine had been logged, the jack pine extended its domain and became the predominant tree over vast areas that had been originally occupied by other species of pine. In the original condition, jack pine was notably free from insect injury and was regarded as a very resistant species. In recent years, however, it has suffered severely from

at least three defoliating insects and one serious scale insect The jack-pine forests of today are in a precarious condition With the right combination of weather conditions, serious insect outbreaks cannot be avoided. In as much as the weather cannot be regulated, an attempt should be made to bring about conditions that will be reasonably free from the danger of insect outbreaks regardless of the fluctuations of weather. For this reason, it is imperative that the jack-pine areas be reduced to approximately their original status by silvicultural means

There are a number of other interesting examples of outbreaks in regions where forest composition has been changed by logging or fires. Among these are the forest tent-caterpillar, in the oak and aspen regions of the Lake States, and the walking sticks, in the oak forests of Michigan. In each case, the same set of conditions preceded the outbreak: an increase of the food for the pest combined with a decrease in the number of the natural enemies of the pest. In these pure second-growth forests the food conditions for birds, and other predaceous animals, are decidedly more limited than they were in the original, mixed forest At the present time, food in these forests is abundant at times, whereas at other times, it is very scarce Because the abundance of an animal is limited by the amount of food available during the period of greatest scarcity, the predators, like the other forms of life in these pure forests, are comparatively scarce. This scarcity is most easily seen among the birds, but it also applies to predaceous insects. Such a reduction in the number of predatory forms must necessarily reduce the effect of environmental resistance upon phytophagous insects. Under such conditions, it should, naturally, be expected that an overabundance of insects is much more likely to occur now than formerly.

Regulation of Density.—In addition to the regulation of forest composition, there are a number of other silvicultural means by which environmental conditions may be regulated with the result that the harmful activities of forest insects will be reduced. One of these is the regulation of forest density. The importance of density has been shown in the case of a number of forest pests. Two notable examples are the locust borer, *Cylene robiniæ*, (Craighead, 1919) and the white pine-weevil, *Pissodes strobi*, (Graham, 1926) These insects will be discussed fully later on

Forest density influences the physical conditions found in the forest by modifying such factors as light, evaporation, air movement, and temperature. This, of course, has an indirect effect on the insect life in the forest. Although the effect of these physical factors is evident from general observation, specific data concerning their effect on insect life in the forest are very scarce. Meager as the knowledge along this line may be, it is known that many of the sun-loving beetles are attracted only to those trees or parts of trees that are exposed to the direct rays of the sun; for instance, the work of the two-lined borer, *Agrilus bilineatus*, is almost entirely confined to shade trees or to trees growing in open stands or to the few exposed branches in a fully stocked stand (Chapman, 1915). The same thing is more or less true of the bronze birch-borer, *Agrilus anxius*, and many other species.

Degree of density is also important in determining the ability of forest trees to outgrow injuries to their terminal shoots. In a fully stocked stand, there is a stimulation to straight growth, whereas, in a scattered stand this stimulation is much less powerful. Furthermore, proper spacing tends to maintain the trees in a healthy condition, and consequently, as a general rule, makes such trees either less susceptible to insect attack or better able to outgrow injury

Selection of Site.—Another important consideration, from the standpoint of silvicultural protection from forest insects, is the selection of site. Under favorable conditions of site, a tree is able to withstand a much greater amount of injury than it could if growing under less favorable conditions. Craighead (1925) has shown that balsam fir is much more resistant to injury by the spruce budworm when it is growing on a favorable site than when it is growing under poor conditions. He goes so far as to recommend growing this species in pure stands on sites where the tree grows rapidly in spite of the budworm menace. It has been questioned whether or not such a recommendation is justified. But the fact remains that vigorous trees survived the budworm outbreak when growing in either mixed or pure stands, whereas less vigorous trees in the same region were almost all killed.

The same is true of other insects. From observations in Minnesota, it appears that thrifty, fully stocked forests are, as a rule, immune to the bronze birch-borer, *Agrilus anxius*. This

insect only becomes injurious in a fully stocked forest after the rate of growth has been reduced because of overmaturity, competition, or poor site conditions. Much of the second-growth white birch in the Northeastern forests is growing on poor soils, and for this reason Agrilus is likely to prevent most of these stands from attaining full development

In the West, site is of considerable importance in determining the susceptibility of trees to the attack of bark beetles. For instance, the western pine-beetle, *Dendroctonus brevicomis*, is much more injurious upon yellow pine growing on comparatively poor sites than it is upon the same species when growing under more favorable conditions

Regulation of Drainage.—Sometimes a site is poor because of an excess of surface water. This may result in an acid soil and other conditions which inhibit growth. In some cases these conditions may be improved by the construction of a superficial drainage system to carry off the excess water Such operations, if they result in a stimulation of growth and the general improvement of the vigor of the trees, will reduce their susceptibility to insect injury.

Another effect that drainage may have in the case of swamp forests is to change conditions of ground cover. There is some evidence that such a change may have an effect upon the over-wintering stage of pests that hibernate in the layer of the duff or in the surface vegetation (Graham, 1928). For instance, if certain tamarack swamps were drained, the surface vegetation of moss and grass would give way to other plants and become more varied. This change in the vegetation by improving food conditions would, in turn, bring about an increase in the number of mice per unit-area. Mice destroy large quantities of larch-sawfly cocoons and their increase, as an indirect result of drainage, will aid in reducing sawfly abundance. Furthermore, it has been shown that hibernation of the sawfly is most successful in the sphagnum hummocks that are so common in tamarack swamps. It is probable, therefore, that a change from the sphagnum ground cover to one representative of dryer land, resultant on drainage, would produce conditions less favorable for hibernation than those now prevailing Still another effect of drainage is the stimulation of tree growth This effect is evident in many partly drained swamps and makes the trees better able to survive partial defoliation.

Selection of Resistant Varieties and Species.—In the foregoing sections, it has been stated that any practice resulting in the production of vigorous, rapidly growing trees helps to increase the resistance of the trees to both attack and injury. It is a matter of common knowledge among foresters that all individuals of a species do not respond equally well to favorable conditions. Some of them will grow more rapidly than others even under practically identical conditions. This ability of some trees to grow better than others is apparently due to physiological qualities within the trees themselves which, if we are to judge from other plants, are probably genetic in character and can consequently be transmitted from generation to generation. If this is true, then the selection of especially vigorous strains will not only result in a greater production of wood products, but may also increase the resistance of the trees to insect attack and injury.

Much has been accomplished in agriculture and horticulture in the selection, breeding, and propagation of trees and other plants possessing desirable characteristics, but in forestry little has been done along this line. The possibilities of developing strains that will be resistant to the attack of certain fungous diseases are beginning to be realized (Hartley, 1927), but the possibility of selection for insect resistance has been almost entirely overlooked.

That there are great possibilities along this line cannot be doubted, but, at the same time, it must be admitted that there are many difficult problems to be solved in the technique of breeding forest trees. For the present, the best that can be done is to select seed for propagation from trees that have those qualities that are desired. By the gradual elimination of undesirable individuals we can cause to a greater and greater degree, the fertilization of the desirable trees by other equally desirable individuals and thus continually improve the strain.

Some of the possibilities of reducing insect damage by selection of resistant trees have been indicated in the discussion of physical factors of environmental resistance in Chap. IV. For instance, the individual norway-spruce trees that are unsusceptible to adelges attack may serve as a nucleus for the development of a resistant variety Likewise, the individual trees that show a resistance to nun-moth attack may provide the parent stock for a nun-moth resistant strain. The development of pines having an unusual ability to produce resin may also serve as a

means of reducing the susceptibility of our pine forests to the attack of dendroctonus beetles. In instances such as those just mentioned, the desirable characters are more or less definite and can be seen or proved to exist by means of tests; consequently, the trees that exhibit these characteristics may be selected without hesitation. In other cases it is not so easy to determine just what characteristics are responsible for the resistance to insect attack or injury.

Sometimes trees may be selected for their resistance to attack, but in other instances selection may be based on the ability of certain trees to overcome injury An example of this possibility has been shown in connection with studies of the pine tipmoth (Graham and Baumhofer, 1928). This insect shows little or no discrimination in attacking trees In western yellow-pine plantations at Halsey, Neb, the trees are all attacked with about equal severity. From this it might appear, at first glance, that selection of resistant trees for tipmoth control would offer little promise of success. But in spite of the uniformly heavy tipmoth injury certain trees are much larger than others of the same age Some may be 6 or 8 feet high while others of the same age, and only a short distance away, may only be a foot or two tall. The tall trees have demonstrated their ability to grow in spite of injury, whereas the others have failed under the test By selecting for seed trees those individuals which have made the best growth under conditions of heavy attack and by destroying before they begin to bear pollen those that have shown themselves to be unsuccessful under such conditions, a strain of yellow pine comparatively resistant to tipmoth injury may perhaps be developed Certainly, the development of resistant varieties of trees is a line of endeavor that should no longer be neglected

There is a possibility that the selection of comparatively resistant species may, in some instances, be more simple and at the same time as effective, as the development of new varieties This possibility was also brought out in the tipmoth study mentioned above. Different species of pine exhibit susceptibility to attack and injury in varying degrees For instance, austrian pine is only slightly injured, scotch pine and jack pine are freely attacked but are able to overcome the injury, whereas western yellow pine is highly susceptible to both attack and injury. If it were not for the fact that both austrian and scotch pine are, for other reasons, less desirable trees for sand-hill

planting than the western yellow pine, their substitution for that species in the Nebraska plantations might be desirable.

Another case in which selection of resistant tree species may be used as a means of protecting forests from insect attack is in the protection of certain forests from injury by the gypsy moth (Mosher, 1915). By avoiding the growing of particularly susceptible species, like oak, aspen, basswood, and a few other less important species, the danger of injury by this insect will be greatly reduced.

From this brief discussion of the relation of silvicultural practices to the abundance of forest insects, it can be concluded that herein lie great possibilities for economical and effective maintenance of balanced conditions in our forests. The possibilities along this line are limited primarily by the knowledge of the factors that regulate all the forms of life in the forest

CHAPTER X

LEAF-EATING INSECTS

The foliage of trees furnishes food for a host of insect species. Many of these are dangerous forest pests but, fortunately, the majority of the leaf-eating insects usually occur in comparatively small numbers. When they are not numerous they will scarcely affect the welfare of the trees, because thrifty trees always have a greater amount of foliage than is actually required for their maintenance When, on the other hand, some leaf-eating species multiplies so much more rapidly than it can be reduced by environmental resistance that it attains tremendous numbers, as they sometimes do, the resultant defoliation will seriously injure or even kill the trees attacked.

DEFOLIATION

Sometimes these outbreaks of defoliators apparently arise with amazing suddenness For instance, the recent outbreaks of the spruce budworm appeared to burst out over wide areas the same year. This was true also of the outbreaks of the larch sawfly. Careful observations will prove, however, that such outbreaks are probably not so sudden as they appear to be. In the case of defoliators, the failure to observe the increasing injury caused by increased numbers of insects may be explained in part by the inconspicuousness of light defoliation. A tree may be stripped of from 25 to even 50 per cent of its foliage without appearing greatly abnormal, provided the defoliation is evenly distributed over the entire crown of the tree. This is illustrated in Figs. 55, 56, 57, 58. Figure 55 represents a normal larch tree in full foliage, Fig 56 shows the same tree after 25 per cent of the leaves had been mechanically removed, Fig 57 shows the same tree with 50 per cent of the foliage gone and Fig 58 shows 75 per cent defoliation. Defoliation is not noticeable until the greater proportion of the leaves has been destroyed When once one realizes the large numbers of an injurious species that may be present unnoticed in a forest, and then considers the tremendously

great possibilities of their extremely rapid reproduction under favorable conditions, the occurrence of apparently sudden outbreaks can be more easily understood Such outbreaks are the result of a disturbance in the biotic balance. They are particularly common where the character of the forest has been

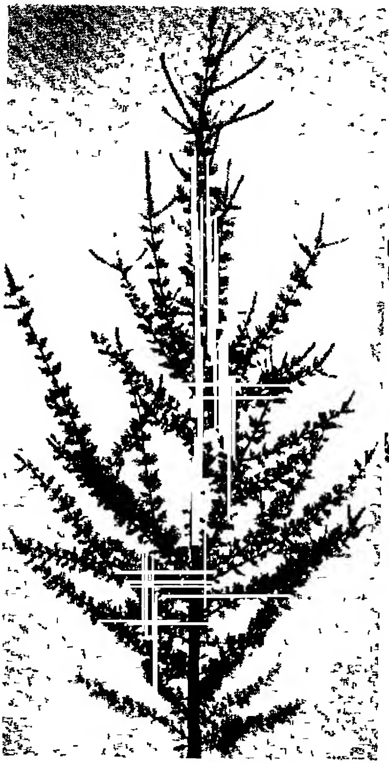


FIG. 55

FIG 56.

FIG 55—A tamarack tree in full foliage
FIG 56—The same tree as that shown in Fig 55 with 25 per cent of the foliage nechanically removed, showing how inconspicuous evenly distributed defoliation nay be

nodified by the action of some external force such as fire, wind, he operations of man, or where natural succession has brought ıbout the establishment of the so-called climax forest type over arge areas.

Effects of Defoliation.—Defoliation injures trees by stopping r checking the elaboration of food materials by the photosyn-

thetic process, by interfering with transpiration, and, probably, by interfering with the processes of translocation of food within the tree. A combination of these effects is reflected in the rate of growth. Defoliation has such a profound effect upon growth that it is possible to trace the history of past outbreaks of leaf-eating insects by studying the annual rings of the surviving

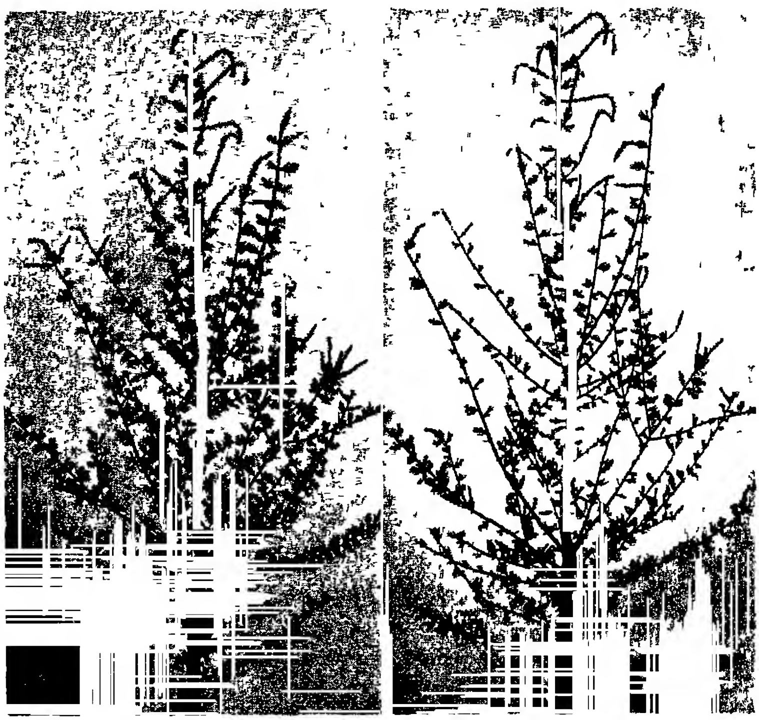


FIG 57. FIG 58

FIG. 57—The same tree shown in Fig 55 with 50 per cent of the foliage removed Even this amount of defoliation is not especially conspicuous

FIG 58.—The same tree shown in Fig 55 with 75 per cent of the foliage removed

trees. Studies of the effect of spruce-budworm defoliation upon the growth of balsam fir and spruce made by Craighead (1924) have proved that growth as a whole is reduced the first year of defoliation. Growth at the top of the tree is usually very much reduced, but at the base it is usually greater than in the years immediately preceding defoliation. Investigations made by the author in budworm-infested areas, other than those studied by Craighead, go further to prove that a widening of the annual

ring at the base of the tree, combined with a narrowing of the same ring at the top, is the usual occurrence during the first year of defoliation. After the first year of defoliation the rings at the base, like the corresponding rings at the top, become successively smaller and smaller, until they are often so narrow that the individual rings cannot be distinguished without the aid of a magnifier In some cases, under conditions of very severe defoliation, there may be no production of wood for a season or more in which case rings may be entirely absent. In other instances, wood may be laid down in certain parts of a tree and not in others This results in the production of incomplete rings. Great care must therefore be exercised in assigning a definite year to a specific ring during periods of defoliation. If a tree survives defoliation recovery is always gradual. As the foliage is gradually replaced, from year to year, the width of the rings increases in similar proportion, until a normal rate of growth has been attained. Similar ring pictures occur in other species than balsam fir and spruce as a result of defoliation, except that t is sometimes difficult to demonstrate the widening of the basal ring of the first year's defoliation.

All species of trees are not equally susceptible to injury from defoliation. Hardwoods are relatively resistant and will often uccessfully withstand three or more years of defoliation. This s due to their relatively large supply of stored food which results n a comparatively rapid replacement of foliage. Correspondngly great resistance to injury from defoliation is also characterstic of deciduous conifers, as exemplified by the larch. Evergreen onifers, like balsam fir or spruce, are more easily killed by his type of injury; for instance, white spruce, hemlock, and robably many others will die as a result of a single complete efoliation (Fig 59). As a rule, more than three successive years f defoliation is fatal even to broad-leaved trees.

Resistance to defoliation injury varies not only with the species ut also with different individuals of the same species. Dominant trees are decidedly more resistant than suppressed individuals of the same species; likewise, trees growing with little no competition are more resistant than trees growing under ss-favorable conditions. The reason for this is to be found in e fact that dominant trees and trees growing in the open withit competition have larger reserves of stored food than those owing in competition with, and suppressed by, other trees.

This large reserve makes it possible for such trees to replace destroyed foliage If defoliation continues after the exhaustion of stored food, a tree is sure to die

The first parts of a tree to die as a result of loss of foliage are the extremities, the twigs, and small roots Craighead (1924) has shown with balsam fir that when the roots have been severely injured the tree is almost certain to die. The same condition appears to hold for at least some other conifers, for example, jack pine, and may apply to conifers in general.

FIG 59 —A hemlock forest in Wisconsin killed as the result of a single defoliation by the hemlock looper. (*A A. Granovsky*)

Trees that have been reduced in vitality by defoliation are much more susceptible to the attack of bark beetles or borers. Frequently trees that might survive defoliation are killed by insects of this type. for instance, stands of western yellow pine that have been defoliated by the pandora moth or the pine butterfly are frequently killed by bark beetles during the years following defoliation

Types of Insect Defoliators.—Generally speaking, defoliating insects may be classified into three groups, according to their habits. Some species, called "leaf miners," feed upon the succulent interior leaf tissues while tunneling between the upper and

ower cuticula (Fig. 36). Others eat all of the leaf except the vas-;ular portions, thus skeletonizing the leaf, leaving only the veins Fig. 60). These are called "skeletonizers" Insects of the hird group may be called the "leaf chewers" for they eat all the eaf tissues (Fig 61). Some defoliators are miners during a part of their developmental period and skeletonizers at a later time

G. 60—Typical work of the birch-leaf skeletonizer, *Bucculatrix canadensisella*, on paper birch (*University of Minnesota*)

thers may be skeletonizers during their early stages and chewers iring the later stages. But there are many species that belong one only, of these three classes during their entire developental period Regardless of the manner of their work, all of ie defoliators have essentially the same effect upon the life ocesses of the tree. The severity of the injury is directly oportional to the amount of chlorophyl-bearing tissues estroyed

The most important tree-defoliating species are found in one of three orders: the Hymenoptera, the Coleoptera, or the Lepidoptera, although there are a few members of other orders that feed upon the leaves of trees (Diptera and Orthoptera) Of the Hymenoptera the family Tenthredinidæ is typically a group of

FIG 61 —The spiny elm-caterpillar, *Euvanessa antiopa* feeding on elm leaves These caterpillars are of the leaf-chewing type. (*University of Minnesota*)

leaf eaters and contains many dangerous forest pests. Of the Coleoptera, the family Chrysomelidæ is the most important group of defoliators. Although, in some instances, members of the Scarabaeidæ, for example, the may beetles which are close relatives of the genus Melolontha of Europe, are very injurious.

But of all the orders of insects the Lepidoptera is the one that contains by far the greatest number of leaf-eating species.

Space will not permit of even a brief discussion of all the tree defoliators known to science, in fact merely to mention the most important species would fill a volume; therefore, only a few typical examples of the different groups will be discussed here. At the end of this section there will be appended a list of some of the more important species that have not been taken up in this discussion.

LEPIDOPTEROUS LEAF EATERS

The members of the Lepidoptera are, on the whole, distinctly phytophagous and by far the majority of species are leaf eaters. A discussion of a few members of this order will follow.

The Spruce Budworm.—One of the outstanding defoliators of fir and spruce in our northern forests is the spruce budworm, *Archips fumiferana* (Fig. 62) This is a native insect that is distributed throughout the range of its host trees. For years it may remain innocuous, a rare and inconspicuous resident of the forest, but when conditions are right it multiplies prolifically and is quickly transformed into a powerful forest devastater Statistics given in Chap I give some idea of the tremendous damage that this insect is capable of inflicting. The causes leading up to these outbreaks are not fully understood, but forest composition and the availability of an abundance of suitable food, appear to be some of the important factors that make these outbreaks possible.

The life history of the spruce budworm exhibits a number of very interesting features. The eggs are deposited during late summer in elongate clusters on the needles of the host trees These clusters are green in color and contain from ten to thirty eggs. The eggs are flattened and overlap one another like shingles on a roof. The young larvæ that soon hatch from these eggs seek out, without feeding, suitable places of concealment on the tree, spin a light covering of silk about themselves, and go into hibernation The silken hibernating cases are called "hibernacula" In the spring, about the time that the buds of the balsam are expanding, these larvæ emerge from hibernation and begin feeding upon the fresh foliage of the host As they work they web the needles together to form a crude shelter. The larvæ de-

velop rapidly and, under favorable conditions, in the cours three weeks are full grown

During the first instars the larvæ are a pale yellowish g with black heads and thoracic shields Later, they become n darker until the general color is brown with black mark They then transform to the pupal stage on the trees No cocoon is spun, but the pupal stage is passed within the web

FIG 62 —The spruce budworm, *Archips fumiferana*, adult moths, pup and larvæ

about the tip by the larva while feeding. The adult moths in July and early August, and soon thereafter they ma deposit their eggs The moths have a wing spread of ne inch and vary in color from grey to copper Two forms insect are found. one on fir and spruce, the other on pine living on spruce or fir tend to be grey, whereas those rea pine tend toward the copper shades

The development of the fir-spruce form of this pest chronized perfectly with the activities of the balsam fir

larvæ emerge from hibernation just in time to find on the balsam fir the fresh foliage that is required for their early development. The black-spruce buds open too late to supply much food for the larvæ at this critical period. Even though the larvæ burrow into the closed buds of black spruce in search of food, they are unable to find a sufficient supply for the needs of their first developmental stage. The white spruce, another host tree, produces abundant fresh foliage at the proper time, but the needles usually

FIG 63 —A Minnesota forest of balsam fir and spruce killed by the spruce budworm (*L. W. Orr*)

ripen up and become hard too quickly to permit full development of the budworms feeding upon them Balsam-fir foliage, on the other hand, not only appears at the proper time but remains green and succulent during the entire period of larval development In eastern Canada the red spruce appears to stand between the balsam fir and black spruce phenologically and also, as we would expect, in degree of susceptibility to budworm attack

If these species of conifers were growing separately, it is probable that the budworm would be able to become epidemic only upon the balsam fir (Fig. 63) When, however, the balsam fir grows in combination with white, black, or red spruce the larvæ

may, by migrating from one tree to another as food conditions require, find ideal conditions for development, in which case both the balsam fir and the spruce will suffer severely. Occasionally in the Lake States black and white spruce grow in mixture on the upland. In this type of forest budworm injury may be severe without the presence of much balsam fir, because under these conditions the larvæ will find suitable food on the white spruce in the early part of the season and later, after the white-spruce foliage has become hardened, they may migrate to the black spruce where they will then find favorable conditions

Thus in the Northeast, balsam fir is the favorite host of the spruce budworm and without this desirable food plant it seems probable that extensive outbreaks, such as we have had in the past, would be impossible except in the comparatively unusual white-black-spruce type of forest. This gives us a clue to a practical and effective control measure and also explains, at least in part, the cause of the terrible outbreak of this pest that has passed over our Northeastern forests during the past decade and a half. Forest fires and logging operations in the latter part of the nineteenth century resulted in a decided change of forest type from pine and spruce to balsam fir so that on vast areas, almost inconceivable in extent, balsam fir became the predominant tree. It was in these areas of almost pure fir that the great outbreaks had their origin. The velocity of multiplication developed by the budworm in these favorable areas, because of the abundance of food and other favorable influences, doubtless made it possible for the insect to attack and kill other near-by forests where conditions were not so favorable for budworm development. It is probable that the forests containing a comparatively small proportion of balsam fir would have been safe from attack had it not been for the adjacent areas of pure or nearly pure balsam fir. One of the immediate problems for forest entomologists is to determine what proportion of balsam fir may be safely allowed in forests of the future

By controlling the composition of woodlands, future disastrous outbreaks of this pest in spruce-balsam forests can doubtless be prevented, to a very considerable extent (Fig 64). The aim in this regulation should be to reduce the amount of balsam fir as much as possible, and, at the same time, to guard against a combination of white and black or white and red spruce. In as much as the larvæ pass from tree to tree, by being born on the

wind as they drop by a thread of silk, they cannot, except perhaps in the first and second instars, travel very far. It is not necessary, therefore, to separate the white spruce from the other spruces by more than a short distance in order to bring about satisfactory control. Thus, under conditions where they are interspersed with other trees in a mixed forest, white and black spruce may be grown in the same forest area with comparative safety.

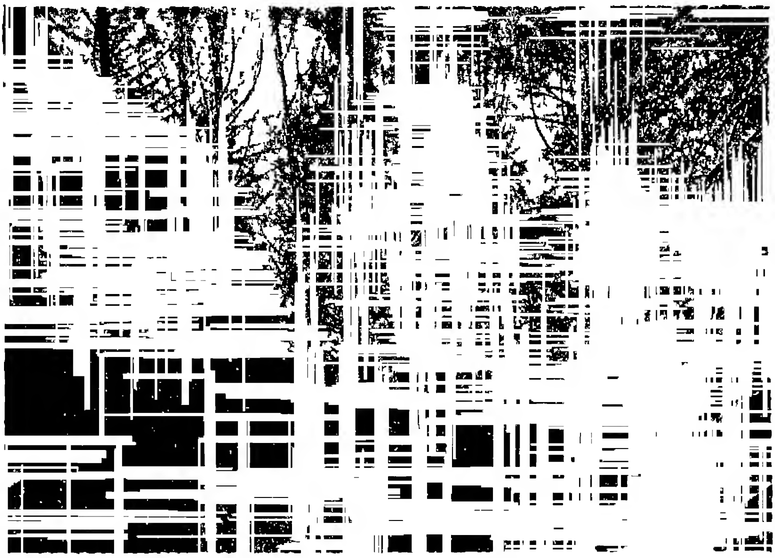


FIG 64 —A forest of douglas fir, in Yellowstone Park, defoliated by the spruce budworm In the West this tree species is apparently comparable with the balsam fir of the East as a favored host of the budworm (*Bureau of Entomology, U S Dept Agr*)

The spruce budworm has, in the past, been regarded as a pest of fir and spruce alone In recent years, however, this species has been observed attacking pines in epidemic numbers, both in the Lake States and in the northern Rocky Mountain region. From preliminary experiments in the Lake States, it appears probable that the budworm on pine, although identical specifically with the spruce-fir form, is a distinct biologic race or variety For although it is possible for the larvæ to continue development and reach maturity successfully after being transferred from spruce or balsam to pine, and vice versa, there appears to be little migration of this sort in nature. The balsam

fir and spruce in the region where the jack pine is infested by this pest remained untouched even though they were close to infested jack pine Likewise, the pest did not migrate from the balsam-spruce forests that were killed by it into the adjacent stands of jack pine. This evidence lends substantial support to the conclusion that the budworm on pine is biologically distinct from the balsam-fir form.

If it is true that the insects do not change readily from pine to other hosts, or vice versa, then each of the two forms may safely be treated from the economic aspect as if it were an individual species, with the result that the problem of control will be much more simple to handle than if the budworm could easily change from one host to another Insufficient data are at hand to make possible control recommendations for this insect on pine except to say that, in the Lake States, the jack pine, *Pinus banksiana*, appears to be the most susceptible of the pines, and it may be that the great abundance of this tree species is an important factor in stimulating the multiplication rate of the pine form of the budworm. It is probable that a reduction of the abundance of this species of pine might help to reduce the danger of the budworm on pine.

On ornamental trees it is profitable to use the direct methods of control These methods are expensive, but certain, and where valuable individual trees are to be protected, they may be applied with profit Spraying or dusting of infested trees with lead arsenate or calcium arsenate at the time the buds are expanding is an effective means of destroying the larvæ of this insect. In dusting, the powdered form of these insecticides may be used either pure or may be diluted with fine, airslaked lime When a liquid spray is used, the poison should be mixed with water at the rate of 3 to 6 pounds of the powder to 50 gallons of water

Questions on Literature

1. When and where was the first reported outbreak of the spruce budworm?
2 List the recorded food plants of this pest in the East and in the West.
3 What secondary insect pests are usually associated with the spruce budworm?
4 How long after trees are attacked by the budworm can they be profitably salvaged? Is this time the same for all species?
5 What species of trees seed up the areas killed by the budworm?
6 When and where have the most important publications concerning the budworm appeared?

The Gypsy Moth.—The gypsy moth, *Porthetria dispar*, is one of the many destructive insect pests that has come to

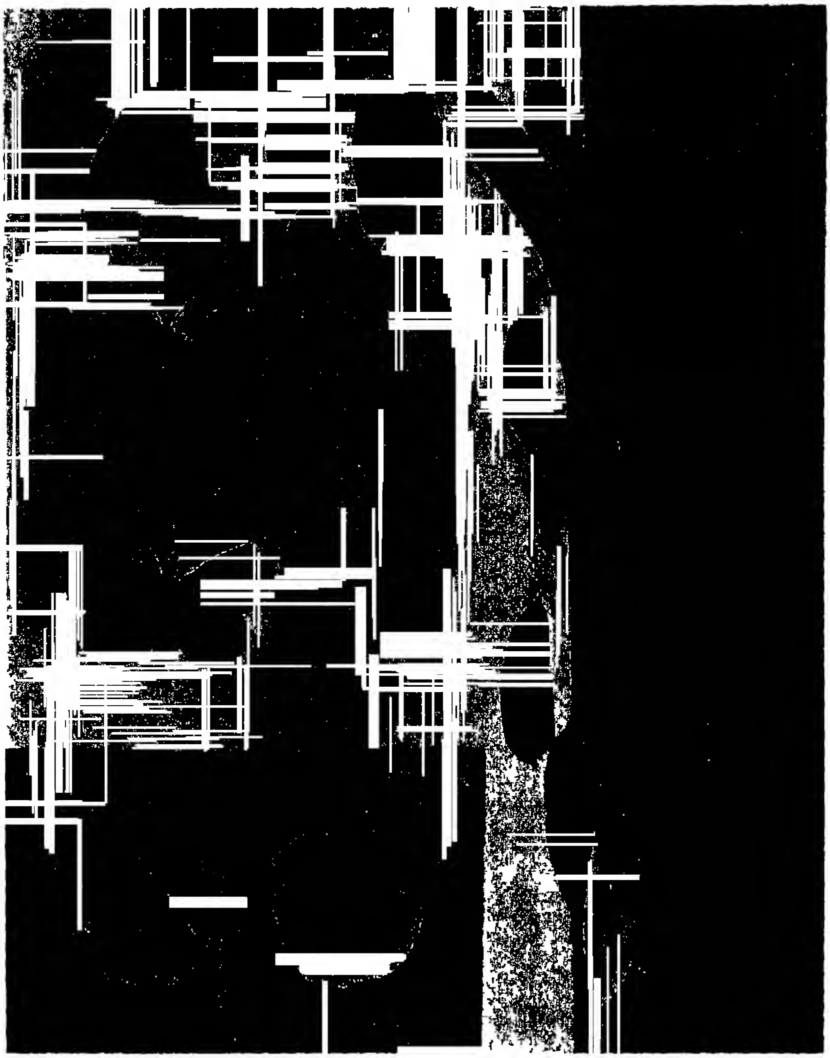


FIG. 65.—Stages of the gypsy moth The large light-colored moth is the female. (*Bureau of Entomology, U. S, Dept. Agr*)

America from foreign lands (Fig 65) This pest was accidentally introduced at Medford, Mass, in 1869, and since that time it has

spread into all the New England states It is particularly injurious to broad-leaved trees, although pines in mixture with hardwoods are by no means immune

The eggs are laid during July in clusters of 400 or more. Since the heavy-bodied female moth is unable to fly, the eggs are usually deposited near and often on the cocoon. The eggs pass

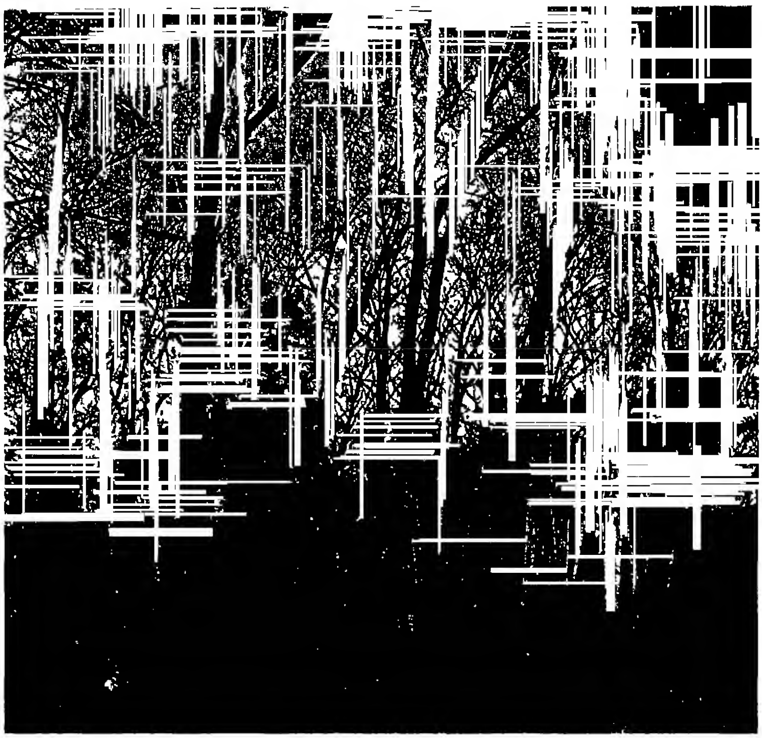


FIG 66—An oak forest in Massachusetts killed by gypsy-moth defoliation. Oak is one of the species most susceptible to gypsy-moth attack (*Bureau of Entomology, U. S Dept. Agr.*)

through the winter, not hatching until the following spring The larvæ feed in the first stage upon the foliage of susceptible trees such as oak, basswood, and aspens, and later they may also feed upon chestnut, hemlock, pine, and spruce If the infestation is severe, the trees may be completely defoliated by the end of June (Fig 66). When full grown, the larvæ pupate, either on the tree or in other convenient places, and after a pupal period of about 10 days, the adults emerge The male moth is brown

in color, whereas the female is white with black markings Unlike the female, the male is a good flier

At first thought, it would appear that a species whose adult females were unable to fly would have little chance of spreading from one locality to another, and would, consequently, be confined to a restricted area and there very easily be controlled This has not, unfortunately, proved to be the case with this pest. One of the important means of distribution for the gypsy moth is wind. The first-stage larvæ are clothed with long hairs which greatly increase the surface area of the body in proportion to its weight. The larvæ at this stage are so light that they can be carried long distances by air currents How far they can be blown in this way can only be a matter of conjecture, but it is known that they have been carried over water for a distance of more than twenty miles That this is one of the important means of gypsy-moth dispersal is indicated by the fact that the most rapid spread of the pest has been in the direction of the prevailing winds. Other means of dispersal are of a more or less accidental character; for example, egg masses or larvæ may be carried on persons or vehicles leaving the infested area

The effect of climatic factors upon the gypsy moth is of great importance both directly and indirectly. A temperature of $-20°$ F is sufficient to kill the overwintering eggs, and, as a result, in severe winters only those eggs that are beneath the snow line, or in other protected locations, survive. This, of course, has an important effect upon the abundance of the species during the following season Cool, moist conditions followed by warm weather during early June are favorable to the development of the wilt disease which is an important natural check of this moth.

Parasites and predators of the gypsy moth have been introduced into the infested area and are, each year, becoming more and more effective, but are still far from giving adequate control. In fact, neither parasites nor predators can be expected to give perfect control. Under present conditions, the best that can be hoped for is to bring about a condition similar to that which obtains in the native home of the pest where the parasites help to prevent outbreaks but do not, by any means, prevent them altogether.

Because of the differences in susceptibility of various tree species, the regulation of forest composition by the application of

silvicultural principles promises to be the most effective method of protecting forests from the gypsy moth By eliminating the most susceptible species, a forest may be made comparatively safe. Much further work along this line is necessary before completely satisfactory methods can be developed.

Ornamental and shade trees may be protected effectively by the application of direct control Spraying with lead arsenate at the rate of 3 to 6 pounds of the powder to 50 gallons of water is very effective In connection with this work, powerful spraying machines and special nozzles designed to throw a spray to the tops of tall trees have been perfected. The use of sticky bands has been found very useful in preventing larvæ from creeping up the trunks of uninfested trees Burlap bands under which the larvæ may congregate during the day are also useful in controlling this pest The caterpillars that collect beneath these bands can easily be killed, mechanically, by crushing them

Questions on Literature

1 What species of valuable timber trees are highly susceptible to gypsy-moth injury? Which are slightly susceptible? Which are immune?

2 What is the general course of procedure followed in introducing parasites from Europe?

3 How many introduced parasites have become established in New England?

4. What effective European predator has been introduced, and why is it more effective than our native species of the same insect?

5. In the light of European conditions, how effective can we expect the natural enemies of this moth to become in America?

6 What types of spraying machinery and nozzles have been developed in connection with the gypsy-moth work in New England?

7 What is the physical nature and chemical composition of the tree-banding material developed in connection with the gypsy-moth work?

The Cankerworms.—Two species of measuring worms, known as the fall cankerworm, *Alsophila pomentaria*, and the spring cankerworm, *Paleacrita vernata*, become periodically epidemic throughout the greater part of the Eastern hardwood-forest region as far south as the Carolinas and Tennessee They also occur in California These species are very similar in appearance and frequently the larvæ are found working together on the same trees. The favorite host trees of these worms are the elms and the basswood, although they also attack a wide variety of other hardwood species (Fig. 67)

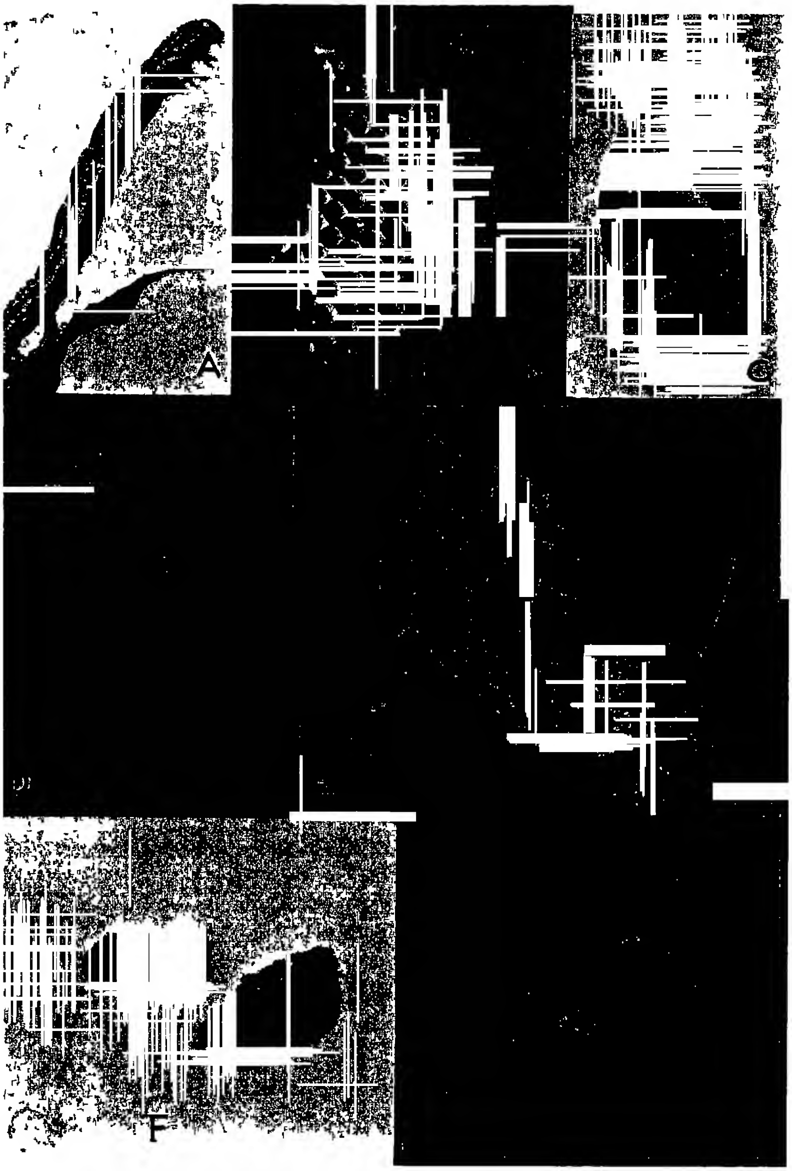


FIG 67 —The fall cankerworm, *Alsophila pomentaria* *A* Full grown larva. *B* *Cluster of eggs* *C* Pupæ *D* Adult male. *E* Adult female in act of oviposition *F*. Pupæ in cocoons *G*. Adult females. Note the absence of wings. (*Bureau of Entomology, U. S. Agric.*)

Although these two species look very much alike superficially, on closer examination they are really very different in every stage (Fig 68) For convenience the most obvious distinguishing characteristics are summarized in the following table:

Stage	Spring cankerworm	Fall cankerworm
Egg	Dull grey, oval, in sheltered locations in irregular groups on trunks and branches	Grey, flowerpot-shaped, deposited in regular clusters on trunks and branches
Larva	Yellowish brown to black in color, only 2 pairs of prolegs	Striped with white and yellow on black, three pairs of prolegs
Pupa	No cocoon spun	Tough, silken cocoon
Adult	Abdominal segments with double transverse rows of reddish spines	Abdomen without spines

The eggs of the fall cankerworm are laid late in the autumn, usually after freezing weather has occurred, whereas the spring species oviposits very early in the spring. The female moths of both species are wingless and crawl up the trees from the ground, where they have pupated, to oviposit in the tree tops The larvæ of both hatch in the spring and feed upon the expanding foliage Four to five weeks are required to complete the larval-feeding period. When full grown, the larvæ drop to the ground and transform to the pupal stage. The fall species spins a tough silken cocoon about itself before pupating, but the spring species passes through the pupal period without this protective covering.

These insects have been little studied as forest pests; therefore no control measures have been developed that are applicable under forest conditions On shade and orchard trees, either banding with sticky bands, to prevent the wingless females from climbing into the tree tops for oviposition, or spraying with arsenicals are effective. Under natural conditions, these species are held in check by parasites and predators of which birds are probably the most important single factor Certain weather conditions, such as cold, wet weather shortly after the larvæ have hatched from the eggs, or damp weather followed by high temperature, are unfavorable

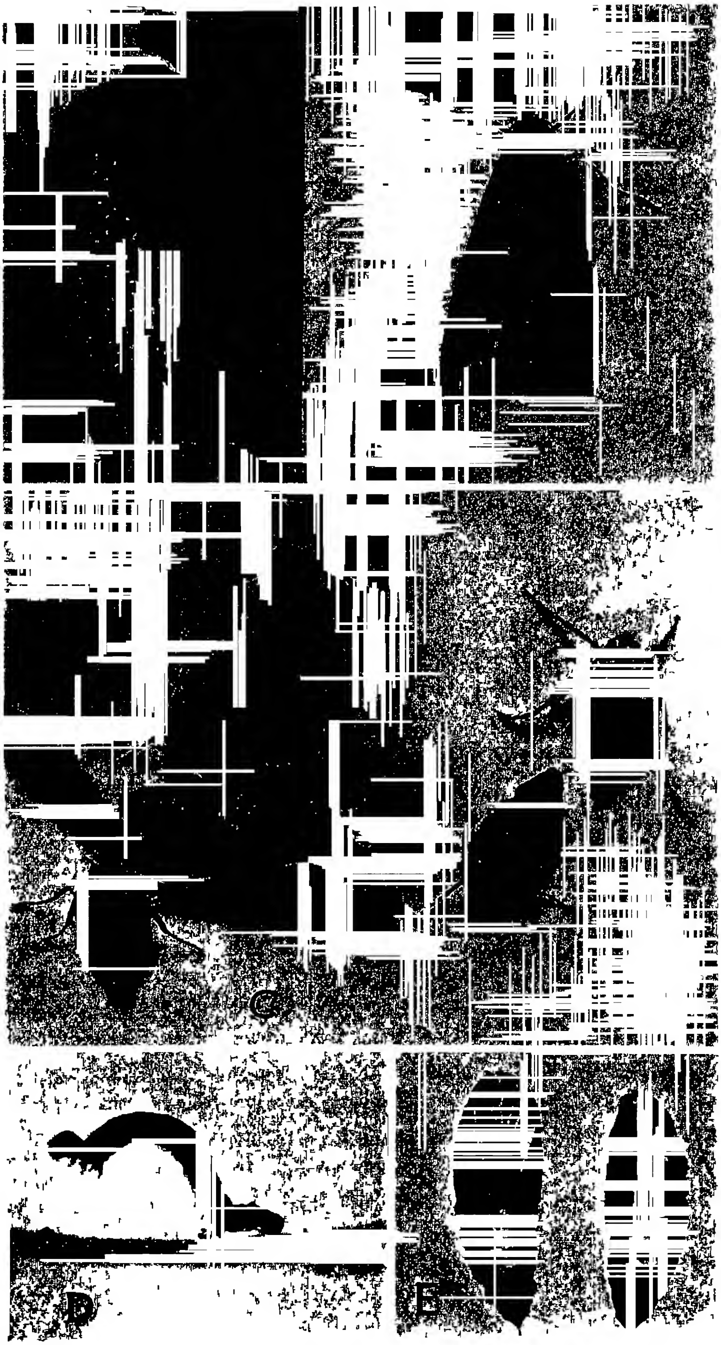


FIG 68 —The spring cankerworm, *Paleacrita vernata* *A* Mass of eggs on

Questions on Literature

1 What variations in length of the incubation period of cankerworms may be expected?

2 What are the favorite food plants of these insects?

3 How are these insects disseminated?

4 What precautions should be taken to insure the effectiveness of banding against these insects? When is this particularly necessary?

5 What natural factors help to hold these insects in check?

COLEOPTEROUS LEAF EATERS

The leaf-eating insects that belong to the order Coleoptera are almost all members of a single family, the Chrysomelidæ,

FIG 69 —The elm leaf-beetle, *Galerucella luteola* 1 A cluster of eggs 2 and 3 Larvæ 4. A pupa 5 and 6 Two adults illustrating the light and dark color forms 7 Larvæ feeding on a leaf 8 A leaf skeletonized by larval feeding. 9. A leaf showing holes made by the adult beetles in feeding (*Felt, "Manual of Tree and Shrub Insects"*)

although the members of the genus Phyllophaga (Lachnosterna) of the family Scarabaeidæ are defoliators in the adult stage.

Only a few of them are important forest or shade tree pests and very little space can be allowed them here.

The Elm Leaf-beetle.—The elm leaf-beetle, *Galerucella luteola*, is another of our introduced pests. It first appeared in Baltimore, Md., about 1834, and since that time has established itself throughout the Middle Atlantic and New England States, and westward into Ohio, Indiana, Michigan, and Kentucky. It is primarily a pest of shade trees and has not as yet become an important factor in the forest (Fig. 69).

The winter is passed in the adult stage. After emerging from hibernation the beetles feed for a time on the expanding leaves of elm trees, and there they later deposit their yellow eggs in clusters of from 5 to 25. The larval feeding period lasts from 2 to 3 weeks. When they are full grown the larvæ transform to the pupal stage on the ground, or in secluded places on or near the trees, where they have been working. The adults emerge in from 6 to 10 days, thus completing the life cycle. There may be two, and possibly more, generations per year depending upon the length of the season.

Spraying or dusting shade trees with an arsenical is the most effective method of controlling this beetle.

Questions on Literature

1. From what part of the world did the elm leaf-beetle come?
2. Is this beetle an important pest in its native land?
3. What is the reason that this beetle has not yet become an important forest pest?
4. How are the pupæ of the elm leaf-beetle protected?
5. Where do the adult beetles hibernate?
6. How can the leaf injury caused by the larvæ be distinguished from that of the adults?

The Poplar Leaf-beetle.—The poplar leaf-beetle, *Lina scripta*, is a serious pest in basket-willow plantations and occasionally is injurious in aspen forests (Fig. 70). With the rapid increase in the area of our poplar forests, and the favorable food conditions resulting therefrom, there is an ever increasing danger of an epidemic of either this insect or the closely related species *Lina interrupta*.

The adult poplar leaf-beetle varies in size but is usually from $\frac{1}{6}$ to $\frac{1}{4}$ inch in length. The background color is yellow and the markings are elongate black spots and lines. The insect passes

the winter in the adult stage. In the spring, the beetles emerge from hibernation and, after a brief period of feeding, deposit their eggs in clusters on the under side of the leaves The larvæ, after hatching, feed upon the foliage gregariously. They are dark-colored, flattened grubs with well developed legs and tapering abdomens. First they skeletonize the leaves, and later they eat irregular holes between the principal veins When they are full grown, the larvæ drop to the ground and there pupate. The length of the developmental period varies with the temperature to which the insects are exposed It is said that only 15 days are required under favorable conditions. The number of generations varies in different localities, according to the climatic conditions, but usually there are two in the Northern States This beetle is generally distributed throughout North America wherever its host plants are found.

FIG 70.—An adult poplar leaf-beetle (*University of Minnesota*)

In plantations of basket willow and on ornamental trees, the poplar leaf-beetle may be effectively controlled by stomach poisons applied in the form of either a spray or a dust

Questions on Literature

1 What factors of the environment are important in reducing the numbers of the poplar leaf-beetle?

2 Where do the adult beetles pass the winter?

3 What species of trees are susceptible to the attacks of the poplar leaf-beetle?

4 How does *Lina scripta* differ in appearance from *Lina interrupta*?

5. What is the geographical distribution of the poplar leaf-beetle?

6. Is this beetle a native species?

HYMENOPTEROUS LEAF EATERS

By far the greater proportion of all the leaf-eating Hymenoptera belong to the family Tenthridinidæ. The adults of this family are called sawflies because of the saw-like ovipositor of the female. The larvæ are, for the most part, very similar to the caterpillars of the Lepidoptera in general appearance and are sometimes called false caterpillars Most of the common species may be distinguished from the true caterpillars by the presence of at least six pairs of prolegs on the abdomen Several

important defoliators of coniferous and broad-leaved trees are members of this group. One of the most outstanding of these is the larch sawfly

The Larch Sawfly.—One of the most serious defoliators of larch, both in Europe and America, is the larch sawfly, *Lygaeonematus erichsonii.* In America, this pest was first reported in New England, in the early eighties, where it was responsible for much damage to the native larch Since this early outbreak the species has played a prominent part in defoliating larch.

Packard and Felt assume that it is one of our uninvited guests, and that it was introduced into America prior to 1880. Hopkins, on the other hand, maintains that it is a native of America. The fact that it remained unknown in this country until 1880, and also that the outbreak appeared to spread gradually westward from the Atlantic seaboard, are evidence in support of the former view A study of the annual rings of old living tamaracks, however, show that this tree has suffered repeatedly from defoliation injury. It is not unreasonable to assume that this injury was very likely due to the sawfly. In Minnesota, the first historical record of larch-sawfly injury is in the year 1909. The ring pictures of old trees, however, show that reduction from defoliation has occurred periodically throughout the life of the oldest trees. In addition to the recent period of reduced growth that started about 1909, there were at least two other periods of heavy defoliation, one just previous to 1880 and another about 1840 Other minor defoliations occurred about 1855 or 1860, about 1870, and in the late 'nineties. Whether or not the larch sawfly is a native or an introduced pest can only be shown by further and more extensive studies.

The life cycle of the larch sawfly is quite similar to that of many other sawflies. The eggs are deposited in the young shoots during the period of rapid spring growth. When first deposited they are translucent and very small. They soon swell, however, as a result of adsorption of water until they protrude from the slit in which they are placed. They are deposited alternately in a double row of slits cut along one side of a rapidly expanding fresh shoot The oviposition injury usually results in killing one side of the shoot, while the other side continues to grow This type of injury results in a marked twisting of the injured tips The abundance of these twisted twigs can be used as an index of sawfly abundance in a stand

The eggs hatch in about a week and the larvæ begin devouring the foliage. They are pale green in color, with black heads They usually work gregariously and, as a rule, they completely defoliate one branch before moving to another. Full growth is reached by midsummer when the larvæ drop to the ground and spin their tough, brown, oval cocoons in the moss or litter beneath the trees. The larvæ remain in the prepupal stage within these cocoons until the following spring when the majority of them transform to the pupal stage and emerge as adults The remainder hold over in the prepupal stage until the second spring, after cocooning, when they, too, transform to the adult stage The adult sawfly is a handsome black insect somewhat over 3/8 inch in length, with a bright orange band about the base of the abdomen (Fig 71).

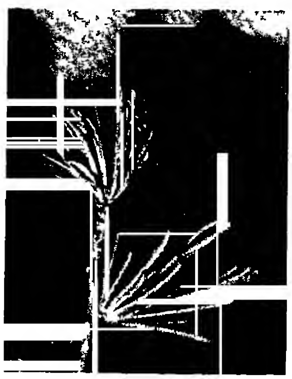


Fig 71 —Adult larch sawfly ready to oviposit in a young larch shoot.

On shade and ornamental trees a spray or dust of lead arsenate or calcium arsenate is an economical and effective control measure. In the forest no effective means of holding this pest in check has, up to the present, been found It has been shown, however, that thrifty, rapidly growing trees are much better able to recover from the effects of defoliation than less-thrifty trees This suggests that light surface drainage, to remove the surplus water from the tamarack swamps, would probably be beneficial in increasing the resistance of the trees Recent experiments indicate the possibility that superficial drainage may so change the character of the ground cover, beneath the trees, that conditions may be made less favorable for sawfly hibernation than in undrained swamps

Questions on Literature

1. From what locality and by whom was the first outbreak of the larch sawfly reported?
2. What species of larch are susceptible to injury by this species of insect?
3. Give the exact distribution of the larch sawfly in Europe and America.
4. What is the sex ratio of this species and what influence should this have upon its biotic potential?
5. What parasites and predators help to keep this pest in check?
6. What secondary insects accompany outbreaks of the larch sawfly?

The Pine Sawflies.—Several species of sawflies are injurious defoliators of pine. Some attack the older trees, like the jack-pine sawfly, *Neodiprion banksianæ* (Fig. 72), while others, of which *Neodiprion lecontii* is a good example, prefer to attack the younger trees.

All of the members of this group deposit their eggs in slits cut in the edge of living pine needles. Some species pass the winter in the egg stage and the young larvæ hatch out in the spring; in other cases, the winter is passed in the prepupal stage within the cocoon Certain species like *Neodiprion banksianæ* have a divided emergence similar to that of the larch sawfly. That is, a part of the adults emerge in the fall following cocooning, while

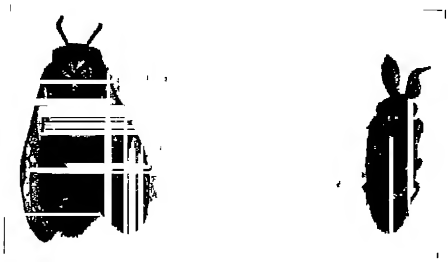


Fig 72 —The jack-pine sawfly, *Neodiprion banksianæ* Adult female and male The female is the larger of the two

a part of them remain for a year longer within the cocoon This protects the species against such seasonal catastrophies as may arise directly or indirectly from adverse weather conditions The jack-pine sawfly appears to be one of the most dangerous of the sawfly defoliators of pine and, during recent years, has been responsible for considerable injury in certain large areas in the Lake States The adults of this species appear in the autumn. The sexes are so different in appearance that it might easily be thought that they were different species The males are only about ¼ inch in length, much smaller than the females, black in color, with feather-like antennae. The females are almost ⅜ inch in length, yellowish brown in color, and the antennae are thread-like.

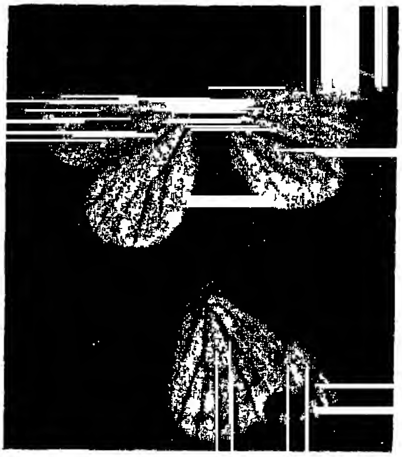
The winter is passed in the egg stage in the needles on the host tree The eggs hatch during May and the larvæ complete their development in a very few weeks Even under cool conditions, the length of the larval period does not usually exceed five weeks

and under favorable conditions this period may be much shortened. In the early instars, the larvæ are a uniform green color with black heads In the third instar, black longitudinal stripes begin to appear which become very strongly marked in the full grown larva. There is but one generation per year. The cocoons are spun in the litter on the ground beneath the infested trees. The larvæ remain in the prepupal stage until late August or September, at which time a part of them transform to pupæ

FIG 73 —Larvæ of the forest tent-caterpillar Note the line of light-colored spots that serve to distinguish this caterpillar from other closely related species (*University of Minnesota.*)

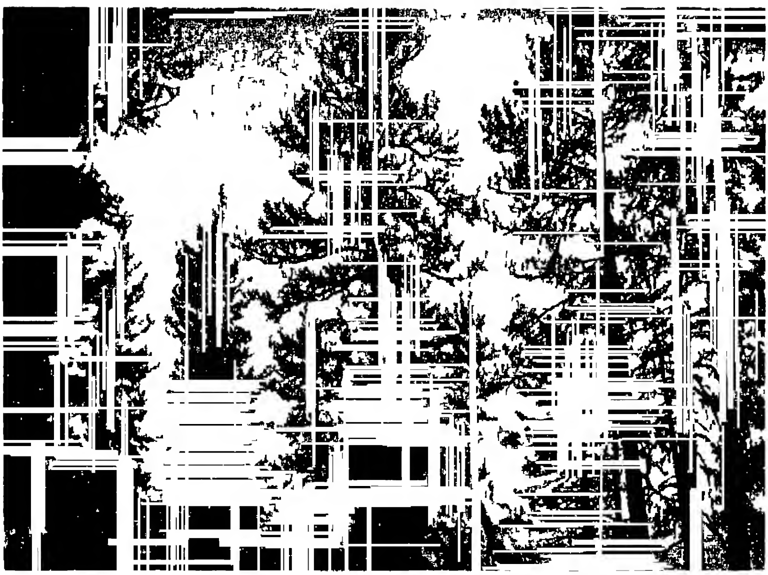
and later to adults, while the others remain in the prepupal stage until the following August or September

Food conditions for this sawfly are much more favorable than they were 20 or 30 years ago. In fact, it is evident that they are ideal when the large areas, formerly covered with red and white pine, that are now occupied by jack pine are considered Parasites are abundant but do not occur in sufficient numbers to hold the pest in check. Apparently, under present conditions, the most important factors that regulate the abundance of this sawfly are the weather factors Heavy rains during the larval stage, or cool moist weather followed by hot weather, have checked



a

FIG. 74.—*a*. Adults of the pine butterfly. (*F P. Keen.*)



b

FIG 74 —*b* Defoliation of yellow pine by the pine butterfly at New Meadows, Idaho (*J C Evenden*)

threatened epidemics during the seasons of 1924 and 1925, either by washing the larvæ from the trees or by making possible the development of a wilt-like disease. In 1926, an early spring followed by late frosts killed many larvæ, thus reducing the numbers of this insect. In spite of these controlling influences, enough adults have emerged each of these years to provide an abundant supply of eggs for the next season Under favorable weather conditions, therefore, which means warm dry weather

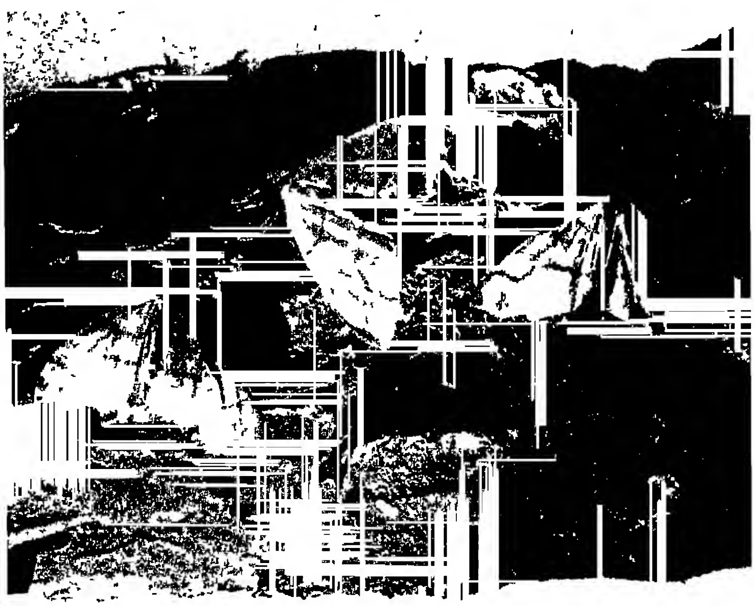


FIG. 75—Adult moths of the hemlock looper, *Ellopia fiscellaria*. (*A A. Granovsky*)

during May and early June, an outbreak of this pest in large areas in Minnesota may be expected

The control of this pest in forests has not been adequately investigated, but it appears that the situation would be ameliorated by a reduction in the area occupied by jack-pine forests, and a return to the better balanced mixed-pine forest. Ornamental trees may be effectively protected against this pest by spraying or dusting with an arsenical while the insects are in the larval stage. It is desirable to apply the poison while the larvæ are still small, because they are much more susceptible at that time,

and, moreover, if treatment is delayed too long, an unnecessary amount of defoliation will occur before they are killed

Questions on Literature

1. How many species of pine sawflies are common in North America?
2. Should European species of this group be considered by American foresters? Why?
3 Which are more injurious to forestry, the species that attack young trees, or the species that attack mature timber?
4. What are some of the important natural enemies of the pine sawflies?
5. Are there any important sawfly pests which attack other trees, either hardwood or conifers? If so, what are they?

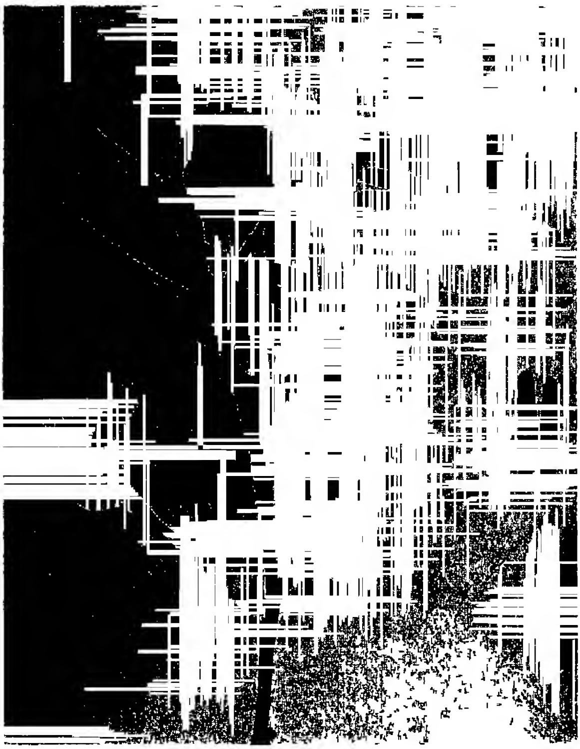


Fig 76—Larvæ of the hemlock looper feeding upon hemlock needles (*A. A Granovsky*)

In the preceding discussion of defoliation and defoliators only a few specific insects have been considered. These will serve to illustrate the general type of injury, and some of the methods of control that may be used in combating insects of this type.

Many other species might have been used equally well as illustrations, and if space permitted they might have been discussed to good advantage. Some of these are the forest tent-caterpillar (Fig 73), the fall webworm, the white-marked tussock-moth, the pine butterfly (Fig 74), and the hemlock looper (Figs 75, 76) For the benefit of those who may wish to study these and other defoliators a list of reading references is given under Leaf-eating Insects in the general bibliography

CHAPTER XI

MERISTEM INSECTS OF THE TERMINAL PARTS

The meristematic tissues, as compared with other portions of a tree, are high in protein content and are, therefore, among the parts held in favor by many insect species. In number of species, the meristem eaters are exceeded only by the leaf eaters The term "meristematic tissue" is here interpreted to include not only the cambium layer proper and the growing tips, but also the adjacent soft portion of the xylem and phloem.

GROUPS OF MERISTEM INSECTS

In a discussion of insects feeding upon the meristematic tissues, we may classify them on the basis of their taxonomic position, or on the basis of the condition of their host, or on the basis of the part of the tree on which they feed

On Basis of Taxonomic Position.—Among the meristem insects are found representatives of several orders. Among the Diptera there are a number of cambium miners that find their nourishment in living trees These dipterous cambium miners do not kill trees and are, consequently, of comparatively little economic importance. It is said, however, that their activities are responsible for certain minor defects of birch and maple, called "pith flecks" Some of the Chironomidæ, called "pitch midges," feed upon the cambium of coniferous trees (Fig 77). The pith that exudes from the tree covers the larvæ and serves as a protection for them Although numerous, this group contains no very dangerously injurious species There are also numerous dipterous species which inhabit the cambium region of dead trees or logs without being true meristem eaters They either feed upon micro-organisms, like fungi, that are found in these locations, or, as in the case of the snipe flies, they are predaceous upon the true cambium feeders Thus the Diptera found in meristematic tissues cannot be regarded from the economic aspect as a very important group.

Among the Lepidoptera, on the other hand, are many important meristem insects Certain species of the family Aegeriidæ, for example, the clear-winged moths, feed upon the meristematic tissues of the trunk and branches of trees. Some of them that attack conifers are known as pitch moths because of the mass of pitch which exudes from the injured tissues When such injuries become overgrown by wood, pitch pockets are formed These defects, when numerous, materially reduce the merchantable value of the lumber produced from the trees. The superfamily Tortricoidea of the Lepidoptera also contains a number of typical meristem insects. The tipmoths and bud miners furnish many illustrations of this group.

FIG 77—A pitch mass on pitch pine caused by the work the pitch midge

But of all the meristem insects those that feed on the cambium are by far the most important group Of these, the larger proportion belongs to the order Coleoptera. The families of beetles that most commonly feed upon cambium are the Curculionidæ, the Ipidæ, the Cerambycidæ, and the Buprestidæ Each of these families contains species that are highly specialized for life in the cambium region, and many of them spend their entire developmental period there Others require the succulent and nourishing tissues only during the early developmental stages, and later are able to obtain nourishment in the solid wood to complete their development. All of these various types will be included in this discussion.

In a brief review of meristematic insects such as this must be, only a few species can be selected for discussion A supplementary list of some other species belonging to this group, with reading references, will be appended in the bibliography, for the convenience of those who wish to expand their study of these insects.

On Basis of Host Condition.—Meristem insects are often referred to as being either primary or secondary in character These are exceedingly convenient terms. Unfortunately, they have been used rather loosely in forest entomological work and

therefore, it is important that the sense in which these terms are used herein be made clear A primary insect is an insect that is able to attack a healthy, living tree and complete its normal development therein. A secondary insect is one that is incapable of attacking and completing normal development in a healthy tree. It would be possible to classify meristem insects on this basis, but in this discussion another arrangement seems more desirable The terms primary and secondary will, however, be used as defined above in connection with certain species

On the Basis of Feeding Place.—For the purposes of discussion, it is more convenient to classify the meristem insects into three main arbitrary groups based upon the part of the tree affected. These divisions are as follows

1 Insects feeding on the terminal parts of trees
   a On twigs, tips, or shoots
   b On small roots
2 Insects confined to the cambium region of the trunk and branches
3 Insects attacking both cambium and wood

The remainder of this chapter will be devoted to a discussion of some of the various meristem insects that feed on the terminal parts of trees, dividing them into two minor groups on the basis of whether the terminal part attacked is above or below ground The other two chief groups will be discussed in the two following chapters.

INSECTS FEEDING ON THE TIPS

This group contains a multitude of insect species but, fortunately, only a comparatively small number of them are sufficiently abundant to be classed as serious pests The members of this group seldom kill the trees that they attack Their chief effect is either to reduce the rate of terminal growth or to cause deformities that reduce the merchantable value of timber In some cases they cause a reduction in both growth and quality An exception to the rule that these insects seldom kill trees is found in cases where these tip destroyers attack seedling or sapling trees. In such instances they frequently kill the little trees

The Pine Tipmoth.—One of the truly injurious tip feeders is the pine tipmoth, (Nantucket pine moth) *Rhyacionia* (*Evetria*)

frustrana. This species was first reported from Nantucket Island, by Scudder in 1876, where it was said to be killing pines 20 to 30 years old A few years later Comstock reported it as being abundant upon Virginia scrub pine near Washington, D. C. Since that time it has been found that this species, including the closely related western variety known as *R frustrana bushnelli*, is generally distributed throughout the pine forests of North America, and is responsible for an immense amount of damage to small pines, both in natural reproduction and in plantations. In the East, this insect has not attracted much attention, since the outbreak on Nantucket Island in 1876, until recently In 1925 another serious outbreak was reported from Cape Cod During the intervening period the species has been present and has reduced the growth of small trees in the East, but it has not been sufficiently abundant to kill trees

The western variety has, in some places, done very little damage, while in other localities it has been very injurious, especially to western yellow-pine seedlings and small saplings In the Lake States and the Black Hills the pine tipmoth can be found in practically every stand of young pine but is never an injurious insect In the sand-hill plantations of the Nebraska National Forest and farther south, on the other hand, this insect has proved to be a most serious pest

The number of generations per season varies with latitude Only one generation occurs in the Lake States and the Black Hills, but in the South there may be three or, possibly, four In the latitude of Nebraska there are two generations This variation is, doubtless, one reason for the difference in economic importance of this species in different localities In the Lake States and the Black Hills, where there is only one generation, little economic injury results; whereas in Nebraska and farther south, where two or more occur, the injury to young pine is severe It is doubtful if this insect will ever be an important pest under climatic conditions that permit the development of only one generation per year.

The life history of the insect in the East and in the West is very similar but varies somewhat more than is usually the case with the same species. The adult moths of both are small, with a wing-spread of less than ½ inch. The front wings are marked with conspicuous copper-colored bands and spots They emerge in the early spring and deposit their eggs on the tips of the young

trees After the eggs are hatched, the tiny pale brown larvæ mine the buds or needles and also the expanding growth (Fig 78) In the latitude of Nebraska the larvæ have completed their growth by the latter part of June. They then transform to the pupal stage which they spend in a thin silken cocoon, within the tunnels that they have mined in the tips. During the first part of July they emerge as adults These moths of the first generation then deposit eggs on the young pine tips for the production of a second generation This second brood is much more abundant than the first and does a correspondingly greater amount of injury. When the larvæ of the overwintering genera-

Fig 78 —Cocoons, pupal skins, adult moths, and larvæ of the pine tipmoth, *Rhyacionia frustrana*.

tion reach maturity, they spin a cocoon in which to pass the winter The eastern variety passes the winter in the tips, while the larvæ of the western variety, when full grown, drop to the ground where they spin their cocoons in the soil beneath the trees

The history of the pine tipmoth on the Nebraska National Forest illustrates well one of the dangers that foresters should guard against in conducting reforestation projects The Nebraska Forest is made up of a series of plantations isolated from native pine Under such conditions, it might be expected that the forest would, at least, become well established before any injurious pests would make their appearance in it, provided, of course, that reasonable precautions were taken to prevent

insect introduction. But because of the desire to obtain quicl results in the early days of this project, the advantage of isolatioı has been sacrificed Instead of waiting the three or four year necessary to produce planting stock from seed in the local nursery forest-pulled stock was shipped in from the Lake States and th Black Hills for planting in Nebraska In as much as this stocl appeared to be healthy its introduction was deemed safe Bu if we examine the available evidence, it would appear that th pine tipmoth found its way into the plantations on some of thes forest-pulled trees The insect, although innocuous in the north became an exceedingly serious pest in its new home.

This experience emphasizes the danger that is always presen in the shipment of planting stock from one region to another Many insect troubles could be avoided if proper precaution were always taken when new plantings were made. Whereve possible, stock for forest planting should always be grown ı the region where it is to be planted When this is impossible then the stock should be obtained from carefully inspecte nurseries. In no case should forest-pulled stock be used fo planting outside the region where it was grown The reasoı especial care should be used to avoid the introduction of insect into new localities is that, very often, a species in a new environ ment is much more injurious than in its old home, where th environmental resistance was higher

The pine tipmoth is one of the very difficult forest pests t control. Up to date, the only method that has proved itsel sure is to pick off and destroy the infested tips before th emergence of the first brood. Neither spraying nor dusting ha proved entirely satisfactory, although a spray of nicotine, wheı applied repeatedly, appears to reduce the injury At the presen time we are forced to class this important pest among thos species that cannot be controlled in the forest

Questions on Literature

1 What precautions should be taken to prevent the spread of this insec into uninfested plantations? How is this pest probably transported?

2 What insect parasites are important in controlling this tipmoth unde normal conditions?

3 Do birds play an important part in regulating the abundance of thı pest? If so, how?

4 How do the larval habits of the two broods differ?

5 At what time of the day are the moths usually on the wing?

The Pales Weevil.—Another important pest of young pines, particularly in the northeastern states, is the pales weevil, *Hylobius pales* This weevil is normally a secondary pest of pine but, under certain conditions, it may be extremely injurious to seedlings. It is said that one important reason for the failure of natural reproduction of white pine, following logging, is the injury to seedling growth by this beetle (Fig. 79)

FIG 79 —A white-pine seedling injured by adults of pales weevil Note how the bark has been gnawed off. (*H. B. Peirson, Harvard Forest Bull* 3)

The pales weevil is a small, brown snout-beetle with light-colored markings on the elytra It breeds in freshly cut logs, stumps, and injured trees, depositing its eggs in the bark during the early spring months The larvæ develop to full growth in the cambium region and are grub-like in form resembling the young of the bark beetles. When full grown, they form pupal cells by cutting depressions in the surface layers of the sapwood and roofing them over with shredded wood. This type of pupal cell is often called a chip cocoon. The adults emerge in the spring months and before they begin ovipositing they require fresh cambium of white pine for nourishment In cutover areas, the small seedlings provide almost the only green white pine

available. For this reason, in the spring, the young trees a attacked and sometimes entirely destroyed by hungry adı weevils

The planting of recently logged white-pine areas should not l attempted until after the second season following logging, unle some means are used either to destroy the brood or to preve the breeding of this weevil in the fresh stumps On loggi areas where a good advance growth of seedlings is alrea established when the large trees are cut, it is advisable to tre the stumps to prevent breeding of the weevil This end may accomplished by barking or scorching the stumps Barki can be done for only a few cents a stump for those averaging inches in diameter and is much cheaper, and more effective, th scorching stumps with fire.

Questions on Literature

1 What is the distribution of the pales weevil?

2 What is the cost of barking stumps for the purpose of controlling t pales weevil?

3 At what time of year should the stumps be barked?

4 How do the tunnels of the pales weevil differ from those of *Ips pini*

5 To what family of insects does the pales weevil belong?

The White-pine Weevil.—One of the important meriste insects of the eastern white pine in the sapling stage is the whi pine weevil, *Pissodes strobi* This pest does not kill trees, bı by killing the terminal shoot of the main stem, it causes the tre to grow forked and crooked and may, under some conditio render them unmerchantable for lumber

The weevils are brown snout-beetles somewhat smaller th the pales weevil and with more sharply distinct white markir on the elytra They pass the winter in the litter beneath t trees. In the spring, they emerge from hibernation to feed a time upon the buds and inner bark of the leading shoots young white pines They then deposit their eggs in chamb hollowed out of the inner bark (Fig 80) From one to th eggs are deposited in each chamber The grub-like larvæ wo downward beneath the bark and destroy the cambium as th proceed (Fig 81). Full growth may be attained before the fi whorl of branches is reached, but in some instances the lar may pass below the second, or even the third, whorl from the t before reaching full development When full grown the lar

fter constructing a pupal cell in the pith or wood, transforms to he pupa and then to the adult (Fig 82). In late July and ugust the young adults emerge; after feeding for a short time pon the inner bark of the new growth, they seek hibernation uarters beneath the trees.

Although this insect is primarily a pest of sapling pines, its ctivities are not confined entirely to such trees. Sometimes arge trees may be attacked but the injury that results is negligible. The age at which the trees are most susceptible is

Fig 80 —A white-pine weevil adult, resting on the terminal buds of a white-ine sapling Feeding punctures may be seen on the buds, and oviposition unctures on the stem below the buds

etween 10 and 15 years After the 20-year mark is passed the roportion of infested leaders drops off rapidly and soon becomes f little consequence

This pest can be controlled in ornamental plantings by pruning rom the trees the injured shoots, or by collecting the adults uring the early spring, by knocking them off the trees into a large et Either collecting or pruning is too expensive to be profitably pplied to forest plantations, but, fortunately, other less xpensive means of control are available

Studies in New England, New York, and Minnesota have all hown conclusively that trees growing in a dense stand are less

subject to weeviling than are trees growing in open stands and, also, that in dense stands the stimulation to straight growth is so strong that practically all weevil injury is outgrown (Fig. 83) For perfect results 1,700 trees per acre is necessary in New York, whereas the standard density of 1,200 trees per acre gives adequate protection under Minnesota conditions.

It has also been shown by Peirson and others that white pines growing under the shade of hardwoods are

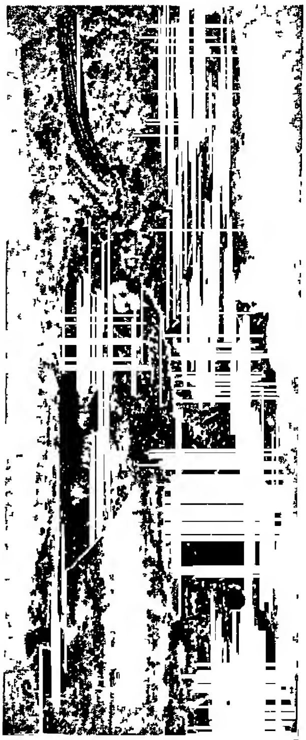


FIG 81.

FIG. 82.

FIG. 81—Section of a white-pine terminal shoot with the bark removed to expose the eggs and larvæ of the white-pine weevil

FIG. 82.—Larvæ and pupæ of the white-pine weevil in their pupal cells within the pith of a white-pine shoot

not attacked by the white-pine weevil. This suggests the possibility of growing white pine under a nurse crop, or under a modification of the shelterwood system, so as to maintain such conditions of light as to be unfavorable for the weevils but still suitable for satisfactory growth of the pines. The planting of white pines in mixture with other pines has also been suggested as a possible means of reducing injury by the weevil In select-

ing trees for such mixed plantings it should be remembered that other trees such as Norway spruce, jack pine, and some other species are also susceptible to the attack of this weevil.

FIG 83 —A scattered stand of young white pine where stimulation to straight growth is lacking Such pines are certain to be heavily injured by the weevil and will seldom produce merchantable timber.

Questions on Literature

1 What species of trees are susceptible to injury by the white-pine weevil?

2 Are there any important parasites that help to reduce the number of the weevil?

3 What birds are probably most valuable in controlling this beetle?

4. What habits serve to distinguish the white-pine weevil from its close relatives?

5 What are some of the other important forest pests that belong to the same genus as the white-pine weevil?

INSECTS FEEDING ON SMALL ROOTS

All of the meristem insects that feed on the terminal portions of trees that have been considered so far in this discussion, have attacked the parts above ground A group that feeds upon the small rootlets beneath the ground will now be discussed. Members of this group are, for the most part, enemies of small trees only, because the roots of the larger trees penetrate the ground below the depth at which these insects normally feed, and are consequently little affected by them. Both trees growing in nurseries and seedlings in the forest, however, often suffer severely as a result of the activities of root-eating insects

The White Grubs.—The most important meristem insects feeding on rootlets belong to the white-grub group represented by the species of the genus Phyllophaga (Lachnosterna) These insects are closely related to the very injurious European genus Melolontha. The white grubs are the larvæ of the may beetle, one of the large, awkward beetles of the family Scarabaeidæ (Fig 84). The beetles are about ½ inch or more in length, heavy-bodied, and brown or black in color. They emerge from the ground in early spring and feed upon the foliage of trees Occasionally, they cause considerable defoliation injury Usually, however, this defoliation is not of serious consequence

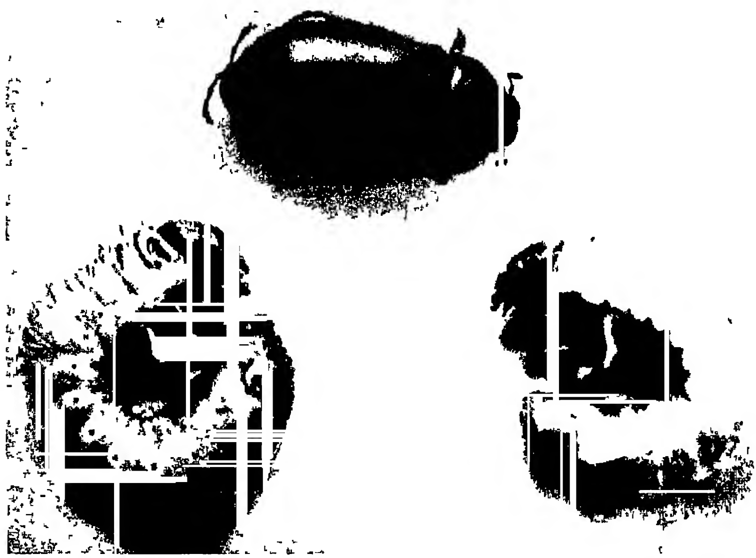


FIG 84.—White grubs Adult and larvæ. (*University of Minnesota*)

The females deposit their eggs in locations where surface vegetation is heavy, as in sod, but they also find favorable locations for their eggs in the nursery in coniferous seed beds The young larvæ that soon hatch from these eggs feed for the remainder of the summer upon organic material and roots near the surface of the soil When winter comes, they burrow deep into the ground and hibernate. The next spring they work their way upward toward the surface and continue to feed on the roots of trees or herbaceous vegetation It is during this second year that they are particularly injurious With the arrival of fall,

they again burrow deeply into the ground for hibernation, and again in the spring they continue to feed upon roots. The larval growth is completed in midsummer, after which the larvæ make pupal cells in the ground where they transform to the pupal stage After an interval of a few weeks, transformation to the adult takes place but the beetles remain in the pupal cells until the following spring. Thus 3 full years is usually required to complete the life cycle In the south, the cycle may be reduced to 2 years, but in the extreme northern part of the United States and in a large part of Canada, completion of the cycle requires 4 years.

These insects are sometimes exceedingly injurious in forest nurseries, particularly in transplant beds. Fortunately they are comparatively easy to control. The eggs are always laid in dense vegetation; therefore, if a nursery is kept clean the only favorable location for oviposition is in the seed beds If these are kept screened with ¼ inch wire mesh, no infestation can occur. If uncovered seed beds become infested no serious injury will occur during the first year after the eggs are laid. If the ground occupied by these seed beds is used for transplants the following season or if the seedlings are not dug during the spring following infestation, heavy losses may be expected

In order to avoid losses on new ground, some cultivated crop should be grown for 2 or 3 years before planting to trees This would give the grubs that are present time to complete their development and emerge. Unless the ground occupied by seed beds can either lie fallow or be planted to some cultivated crop for 2 or 3 years after a crop of seedlings has been dug, the seed beds should be screened to prevent access of the adult beetles to the seedlings In this way oviposition can be prevented Ground in a nursery that is lying fallow should be kept clear of grass or weeds. Otherwise the beetles will oviposit there

In cases where proper precautions have not been taken and a nursery has become infested, the application of mechanical control measures will be necessary. This is a difficult matter and sometimes cannot be accomplished at all in heavy soil. In light soils, however, a tool resembling a steel brush has been successfully used in destroying the larvæ. By repeatedly forcing the wires of this brush into the soil most of the grubs in a small area may be killed Obviously, this is an expensive method of

control in a country of high labor cost and is ordinarily unnecessary when proper precautions are taken.

Questions on Literature

1 About how many species of white grubs are common in the Northeast the Lake States, the Northwest?

2 What name other than may beetle is applied to the adults of the white grubs?

3 How does the life cycle of the may beetle differ from that of the European Melolontha?

4 What methods are used in Europe for Melolontha control?

5 What are some of the important enemies of white grubs?

Other Small-root Insects.—In addition to the white grubs there are a number of insects of lesser importance that feed upon the small roots of trees. Some of the cecidomyid gall insects attack the root meristem and there produce galls Some other members of the Diptera also may attack the small roots but they are all of very minor importance from the economic viewpoint Some of the soil-inhabiting insects, like the wireworms, will feed upon the small roots and, if numerous, may cause considerable injury to seedlings either in the forest or the nursery

The wireworms belong to the family Elateridæ of the order Coleoptera and, like the white grubs, feed in the larval stage upon vegetable material, including plant roots. The adults of this family are commonly called "click beetles." They are heavily chitinized, flattened beetles resembling some of the buprestids in form The larvæ are slender, elongate, and heavily chitinized; hence the name *wireworm* The legs are feebly developed.

These insects are found most commonly in comparatively heavy, moist soil which contains a considerable amount of undecayed plant materials. Small trees growing in such locations are most likely to suffer injury from these pests No satisfactory method has been developed for the control of wireworms; forest nurseries, therefore, should not be established on soil in which wireworms are abundant

Questions on Literature

1 Why are the adults of the wireworms called click beetles?

2 How long is the life cycle of the wireworm?

3 What other beetles that resemble wireworms occasionally injure the roots of trees?

4. Are all wireworms found in the soil?

5 What are some of the natural enemies of wireworms?

CHAPTER XII

MERISTEM INSECTS OF THE CAMBIUM REGION

The insects of this group are commonly known as cambium insects. They live in the cambium throughout their developmental period and, with certain groups, the Ipidæ for example, even the adult life is spent for the most part in that region. Among the cambium insects are some of our most destructive forest pests and, also, many species that never kill or seriously injure healthy trees. Representatives of several insect orders live in the cambium, but most of the cambium insects belong to either the Lepidoptera or the Coleoptera. For purposes of discussion, it is more convenient to divide the cambium insects into two arbitrary groups, namely, the cambium borers and the bark beetles Insects belonging to both these groups feed upon the cambium during the developmental stage, but in the former group only the larvæ, and in some cases the pupæ, are found in that region, whereas in the latter group both larvæ and adults inhabit the cambium

CAMBIUM BORERS

Among the cambium borers we find members of both the Lepidoptera and the Coleoptera, the latter predominating Among the Lepidoptera the pitch moths are perhaps the most common (Fig. 85). There are a number of species of these moths, but their life cycles and types of injury are usually very similar. Therefore the well-known pine pitch-mass borer adequately illustrates these lepidopterous cambium insects.

The Pine Pitch-mass Borer.—The adult of the pine pitch-mass borer, *Parharmonia pini*, is one of the clear-winged moths of the family Aegeriidæ. In shape and coloring, these moths suggest wasps; consequently, members of this family are frequently cited to illustrate protective coloration and mimicry. This insect does not kill trees but causes defects that lower the value of lumber made from the injured trees

The adult moths appear in midsummer and deposit their eggs on the bark of the host tree, usually at the edge of a wound The

larvæ, which are typical caterpillars in form, hatch from the eggs and spend two or three years in the developmental stages During this period they feed in the cambium region where each larva excavates a broad chamber near the point where the egg was deposited. After the larvæ have become full grown, which process may require several years, they transform to the pupal stage in the pitch mass that has accumulated over the burrow

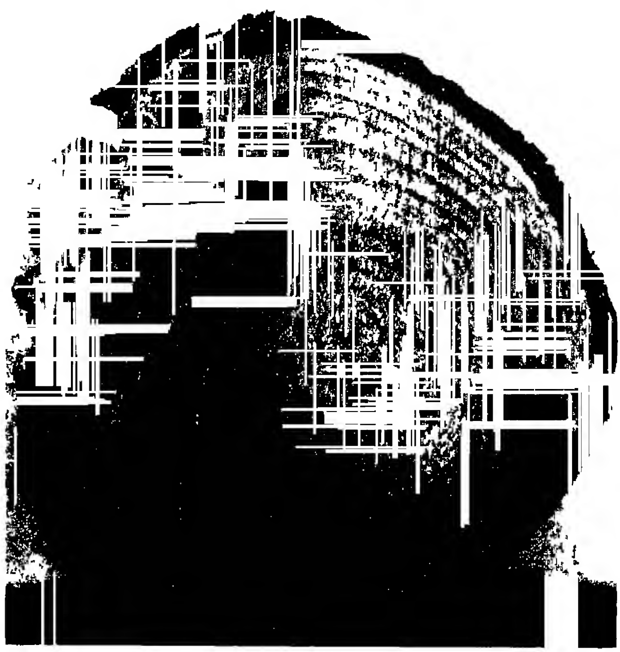


FIG 85—A pitch pocket in the process of formation in douglas fir The growth of the tree is gradually enclosing a mass of pitch exuded from the tunnels of the douglas-fir pitch-moth. (*Bureau of Entomology, U S Dept Agr*)

Just before the adult moth is ready to emerge, the pupa works the anterior portion of its body out of the sticky mass of resin, so that the moth may emerge without becoming entangled in the soft mass.

The control of pitch moths is very difficult in the forest The systematic examination of the trees, in order to secure the destruction of larvæ by mechanical means, has been recommended for certain species, but such an operation would be economically justifiable only where extremely severe infestations occur in

very valuable timber Because the moths seek wounds and scars for oviposition, the prevention of mechanical injuries to the tree, or any treatments which tend to stimulate rapid healing of wounds, will reduce the amount of injury by the pitch moth. Thrifty trees growing on suitable site conditions are less susceptible than are trees growing on the poorer sites On shade and ornamental trees, of course, the process of destroying the larvæ is both effective and economically justifiable.

Questions on Literature

1 What are some of the other members of the pitch-moth group that are injurious to forest trees?

2 What is the length of the life cycle of the pine pitch-mass borer?

3 What important pests of orchards belong to the same family as the pitch moths?

4 Why cannot the pine-mass borer be controlled by the application of a spray to the trees?

By far the greater number of the important cambium borers belong to the order Coleoptera Among them are many of the Buprestidæ, the metallic wood borers or flat-headed borers, and a number of Cerambycidæ, the long-horned or round-headed borers These families of beetles contain some of our best known forest pests Some of them are primary, and are able to attack healthy trees and complete their development therein Others are secondary, and are only able to complete their development in decadent or dying trees, and in freshly cut logs The most important species of insects in this group are, of course, the primary species The secondary species of cambium insects play an important part in hastening the decay of forest waste by opening the way through the bark for fungous infection, but otherwise they are of little direct importance. This is not true of the secondary insects discussed in the next chapter, those that not only work in the cambium region but also bore into the solid wood A few examples of the cambium beetles will now be considered. Several of the primary species that are representative of the important families mentioned above will be discussed.

The Sugar-maple Borer.—Among the cambium borers one of the most striking and best-known examples is an insect of the family Cerambycidæ called the sugar-maple borer, *Glycobius (Plagionotus) speciosus* This insect confines almost all of its larval activities to the cambium region, and only when it reaches

its full growth does it penetrate into the sapwood where it forms its pupal cell.

The adults are beautiful black beetles, almost an inch in length, with yellow markings (Fig 86). They emerge from the trees in midsummer and deposit their eggs in slits, which they cut with their mandibles, in the bark of hard maple trees, usually on the trunk The larvæ soon hatch, tunnel through the bark, and take up their injurious labors in the cambium region Here the larvæ pass the winter and in the year following they accomplish the greatest injury. Since the larvæ tend to tunnel around the tree rather than lengthwise of the trunk, a very few of them working close together may girdle a tree and thus kill it Usually, however, the larvæ are not gregarious and consequently the infested tree does not immediately die. By killing patches of bark the way is opened, however, to the attack of other disease organisms The larvæ attain full growth by the end of the summer following the year of oviposition At that time they tunnel into the wood where the pupal cell is formed, there the second winter is passed in the prepupal stage The pupal stage occurs the following summer just previous to the emergence of the adults Thus a period of two years is required for the complete life cycle of this insect.

FIG. 86 —The sugar-maple borer, *Glycobius (Plagionotus) speciosus*, 1 Adult beetle 2 Young larva 3. Fully grown larva cutting into the wood. (*Felt, "Manual of Tree and Shrub Insects."*)

To control this insect in shade trees, it is advisable to destroy badly infested trees. In moderately infested ornamental trees, the larvæ may be cut out and destroyed. This work should be done as early as possible in the life of the insects so that the resultant wounds may be small and, as a result, quick to heal.

The presence of young larvæ is indicated by the exudation of frass and sap from the egg slits In woodlands and groves, the presence of a luxuriant undergrowth is said to reduce the danger of infestation by this beetle The beetle is a light-loving species; hence trees in the open are more subject to attack than are trees in closed stands This fact should be borne in mind when improvement cuttings and thinnings in hardwood forests are contemplated

Questions on Literature

1 What other closely related insects might be confused with the sugar-maple borer?

2 Does this borer attack other maples than the sugar maple?

3 How many eggs does a single female of this species usually deposit?

4 What appearance is characteristic of the trees infested with this insect?

5 Is the sugar-maple borer a native or an introduced pest? How do you know?

The Two-lined Borer.—The two-lined borer, *Agrilus bilineatus*, is a member of the family Buprestidæ The members of this family are sometimes called the metallic wood borers, because of the metallic coloration that is so characteristic of the adults; or sometimes they are called flat-headed borers, because of the flattened prothorax which at first glance appears to be the head of the larva. Many of the members of this family are cambium-wood insects and some are wood insects These will be taken up in succeeding chapters. But some of them, like the two-lined borer, work during their entire developmental period in the cambium region

The two-lined borer attacks chestnut, oaks, and, possibly, beech. This species is generally distributed east of the Rocky Mountains. The beetles after emerging in late spring and early summer deposit their eggs upon the bark of their host trees They are black beetles about ½ inch in length and rather slender in form These beetles are more or less gregarious, and the eggs that the females lay are usually deposited rather close together on attractive portions of the trunks and larger branches of the host tree The eggs are tightly fastened to the bark, and, in hatching, the young larvæ cut their way through the under side and bore directly through the bark to the cambium. There they tunnel transversely between the bark and wood Working in groups as they do, they promptly girdle the infested portion of the trunk or branch and may, if they are sufficiently numerous,

kill a large tree in a single season (Fig 87). The larvæ are elongate flattened grubs with the head invaginated into the somewhat enlarged flat prothorax By autumn the larvæ are full grown They tunnel into the bark and there form pupal cells in which they pass the winter as prepupæ. In the spring they transform to the pupal stage and in June emerge as adults.

The two-lined borer is a light-loving insect The adult beetles like to bask in the sun For this reason they are much more

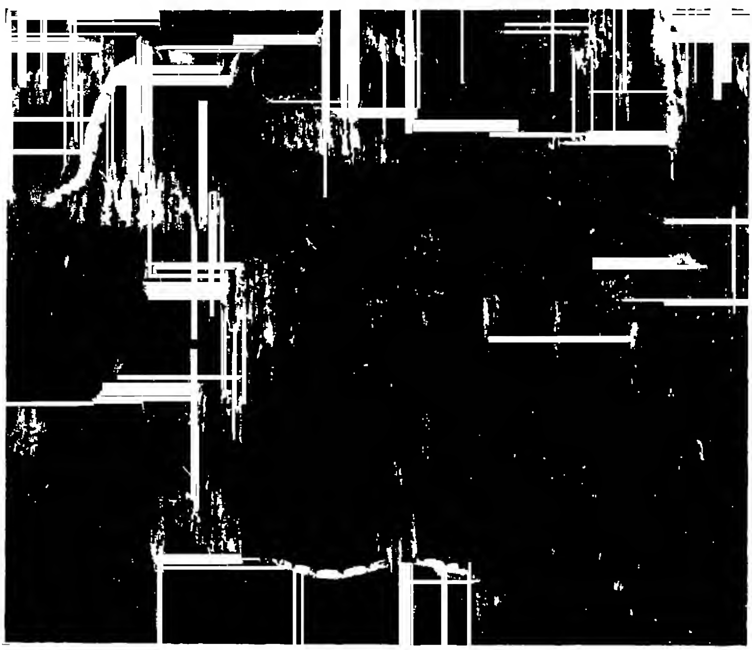


FIG 87 —Larvæ of the two-lined borer, *Agrilus bilineatus*, tunneling in oak (*University of Minnesota*)

likely to deposit eggs upon trees that are standing alone than they are upon forest trees. This species is, therefore, more injurious to shade trees than to trees growing under forest conditions In some localities, the two-lined borer is frequently found working in conjunction with the root rot *Armelaria mellia*, a parasitic fungus. Armelaria, unlike the borer, appears to attack most frequently trees growing in woodlands and kills groups of trees Around the edges of these killings, the two-lined borer finds a desirable place to work and usually joins with the fungus in con-

tinuing the destruction of the trees A tree that is heavily infested by this insect is almost certain to die; the tunnels resulting from a light attack, on the other hand, are often overgrown by healthy vigorous trees

One of the methods frequently suggested for the control of this pest is to cut and bark all infested trees before the adult beetles emerge in the spring Control by this method must be a community proposition, for the efforts of an individual owner, without the support and cooperation of his neighbors, are hopeless Even when an entire community joins in the work, there is danger of the beetles flying in from outside and reinfesting the area.

Almost the only means for controlling the two-lined borer on a small scale is by the use of a repellant spray Whitewash, lime sulphur, and iron sulphate have a repellant effect when applied to the trunk and large branches, in that they make the tree less attractive to the beetles. Unfortunately, most repellant materials lose their efficacy as a result of the effects of rain; hence, in order to insure success, frequent applications of the repellant must be made during the period of oviposition.

Other Species of Agrilus.—Several other species of the genus Agrilus are dangerous enemies of forest and shade trees The oak twig-girdlers are particularly injurious. These girdlers attack small branches or twigs and usually carry their tunnels toward the base of the branch in which they are working At intervals they circle the branch and thus girdle it at that point These insects may kill branches as large as two inches in diameter, thus they stand in an intermediate position between the meristem insects of the trunk and larger branches and those that work on twigs

In many parts of the United States the bronze birch-borer, *Agrilus anxius*, has become so abundant that the successful growing of birch for shade trees is almost impossible Even in the forest, it is becoming more and more prevalent (Fig 88) It is very similar in appearance and habits to the two-lined borer It is most seriously injurious to overmature stands, but is also a dangerous pest of birch that is growing slowly on poor quality sites. Like the two-lined borer, the bronze birch-borer is a lover of sunlight It is for this reason that shade and other ornamental birches are so often attacked by this insect For the same reason, birch trees left when heavy thinnings or cuttings

are made in the forest are very likely to succumb to its attack In the northern spruce and balsam forests that have been heavily thinned by the spruce budworms, the white birch, left exposed to the sunlight by the opening up of the forest, is now dying

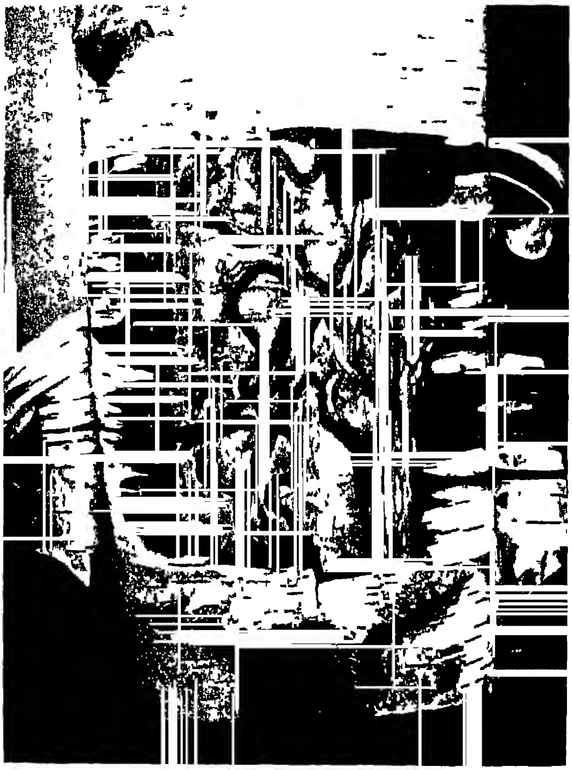


FIG 88—Work of the bronze birch-borer, *Agrilus anxius*, in white birch (*University of Minnesota.*)

Questions on Literature

1 How does the larva of Agrilus differ in appearance from most of the other Buprestidæ?

2 Are there other important pests of hardwood trees, other than oak and birch, that are members of the genus Agrilus? If so, what are some of them?

3 What peculiarities of habit are characteristic of Agrilus larvæ at the time of moulting?

4 Of what does the food of the adult beetles consist?

5 Does any species of this genus attack coniferous trees?

BARK BEETLES

We now come to the second arbitrary group of cambium insects, the bark beetles of the family Ipidæ (Scolytidæ) They comprise a very large family of the Coleoptera. A large proportion of both the genera and species of this family are represented in North America. Each larger group of the family has a characteristic manner of working, and there is much variation in the details of the life cycle of different species even within the genus. Practically all the members of this family are tree pests

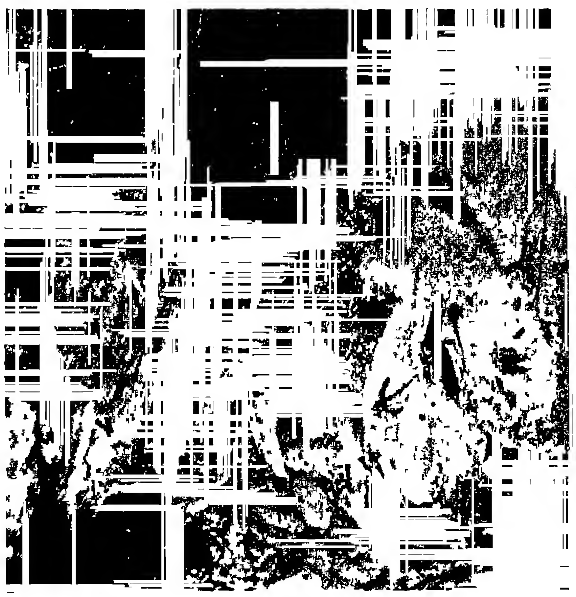


FIG 89 —A gallery of the red turpentine beetle, *Dendroctonus valens*. Note the egg nitches cut along the side of the gallery

General Characteristics.—Certain traits and habits are common to all the bark beetles For instance, all of the true bark beetles excavate galleries in the cambium region and there deposit their eggs. The larvæ, that hatch from these eggs, work outward in the succulent tissues of the inner bark and cambium until they are full grown There they form pupal cells, sometimes in the outer sapwood, sometimes between the bark and wood, and sometimes in the outer bark The pattern formed by the tunnels is specific in character (Figs 89, 90). An expert

can usually easily identify a species of bark beetle by its work alone

Most of the bark beetles are secondary in character, but a few species are important primary pests Some appear to stand in the middle ground and are usually secondary, although they may occasionally become primary. Only under favorable

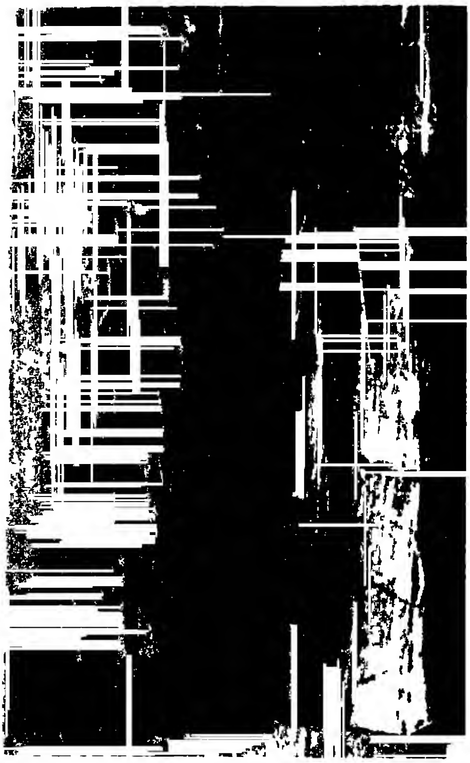


FIG 90—Tunnels of *Ips calligraphus* in white-pine bark This type of gallery, with the central nuptial chamber and radiating galleries, is characteristic of many of the Ipidæ.

conditions are these intermediate forms able to attack and kill living trees. The balsam-fir bark-beetle, *Pityokteines sparsus*, is an example of a bark beetle that appears never to be primary. *Ips pini*, *Ips perroti*, and *Pityogenes hopkinsi* are usually secondary, but, when they occur in excessively large numbers, they may occasionally kill a few young trees Undoubtedly, trees are occasionally killed by these species. Other species of Ips,

articularly some of the western species, are apparently primary nd often top-kill trees.

The group which contains most of the bark beetles that are enerally considered to be primary pests of trees, is the genus)endroctonus. In the mature and overmature coniferous)rests of the West, Dendroctonus beetles have destroyed mber aggregating many million board feet Not all of the)ecies of this genus can be regarded as being primary because)me of them seldom kill trees Examples of these are the red ırpentine-beetle, *Dendroctonus valens*, and the black turpentine-eetle, *Dendroctonus terebrans*. Others, like the Black Hills beetle, *'endroctonus ponderosæ*, the mountain pine-beetle *Dendroctonus ɔonticolæ*, and the douglas-fir beetle *Dendroctonus psudotsugæ*, ppear to prefer to attack living healthy timber

One of the most important factors that determines the degree) which a bark beetle may be primary, is its ability to resist the ow of resin or sap. The more vigorous a tree, the greater will e the flow and the more resistant it will be to the attack of ımbium borers. Some insects, like the pitch-mass borers and ther Aegeridæ, are able to live without difficulty in a sticky mass ' resin. Most of the bark beetles, however, are not so well dapted to this mode of life and are easily overwhelmed by ɛudations of healthy trees. These are the non-primary species he Dendroctonus beetles, on the other hand, are able to with-ιand a copious flow of resin for a brief period, but if the flow)ntinues they also become overwhelmed Thus a single indi-ıdual of even the Black Hills beetle, one of the most resin-'sistant species of the genus Dendroctonus, is unable alone to .tack a tree successfully To be successful, the beetles must ıter a tree in large numbers so that the flow of resin or sap is uickly checked by the combined activities of the attacking varm of beetles.

The Black Hills Beetle.—The Black Hills beetle, *Dendroctonus ɔnderosæ*, has been selected as a representative of the important ɜnus Dendroctonus. This beetle is decidedly primary in ıaracter and has been responsible for the death of thousands ' trees in the Black Hills, eastern Wyoming, Colorado, and Utah. he adults are stout, black or dark-brown beetles about ¼ inch ι length Winter finds the individuals of this insect species in very stage of development from eggs and young larvæ to adults he eggs are seldom able to winter successfully, but larvæ,

pupæ, or adults are able to hibernate. These overwintering forms continue their activities as soon as weather permits in the spring. Since the individual rate of development varies, even in the same locality, owing to differences of temperature and other conditions, a decided overlapping of broods results The height of adult emergence comes in midsummer. The beetles usually attack a tree in large numbers In cases where they have attacked in small numbers, they have not been successful because of the excessive flow of resin. When a tree is attacked by many beetles at the same time, this flow of resin is checked. In fact, the trees may sometimes be killed so quickly that practically no resin flow occurs.

The parent beetles cut long, longitudinal galleries in the cambium region, called primary or mother galleries. The eggs are deposited along the sides of these galleries. The young grub-like larvæ work out at right angles to the primary gallery, feeding upon the soft tissues as they proceed until they are fully developed Those coming from the eggs deposited during the first of the season may complete the larval stage and transform to pupae, or occasionally to young adults, by the autumn of the same year, but most of the larvæ pass the winter in the developmental stage and continue their growth the following spring and early summer At the end of the larval tunnel a pupal cell is formed in the inner bark With certain other species of Dendroctonus beetles, *Dendroctonus brevicomis* for instance, the pupal cells are formed in the corky layers of the outer bark. The habits of pupation play an important part in determining the details of control, as shown in a later paragraph After passing through the pupal stage, the young adults of the Black Hills beetle feed on the inner bark with the result that the pupal cells become connected Later, the beetles emerge and seek fresh trees in which to oviposit

This species attacks several species of pine The favorite host, however, is the western yellow pine, *Pinus ponderosa* The first evidence that a tree has been attacked is the formation of pitch tubes at the mouth of the entrance holes These tubes are formed by the exudation of resin that the tree pours into the burrow and the beetle pushes out of the burrow. Even though a tree may be completely girdled by these beetles, the foliage remains green until the following winter or spring when the needles become first pale and then yellowish. Such trees are

called "sorrel tops." Late in the season following infestation, the needles become reddish brown, and the trees are called "red tops" In the third season the needles fall and the trees become dark in color and are then termed "black tops" The fourth year or later the tops become broken Thus it is possible to determine the approximate age of infestation by the appearance of the trees

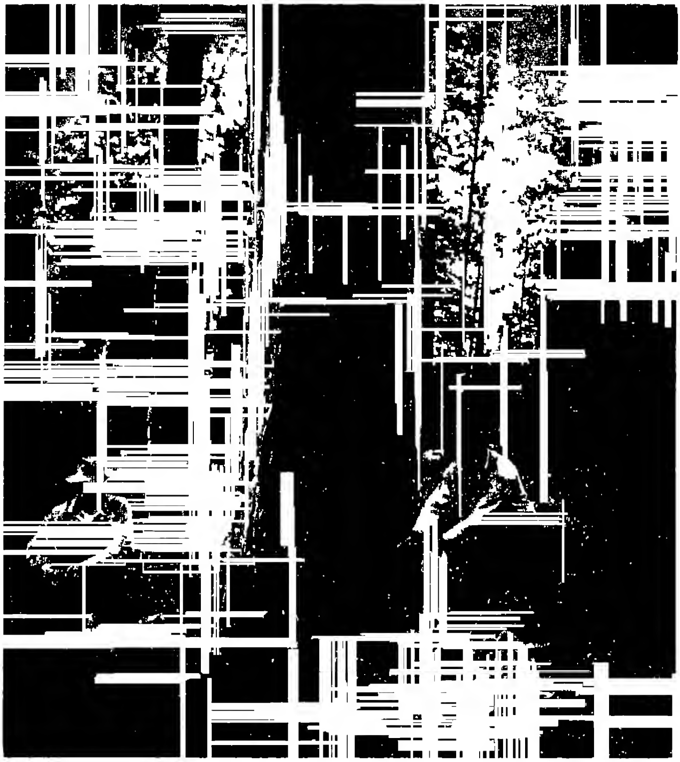


Fig 91—Felling a western yellow pine infested by *Dendroctonus brevicomis*. (*F P Keen*)

Much work has been done in connection with the control of these and other Dendroctonus beetles. The mechanical methods of cutting and barking infested trees before the emergence of the brood have been most frequently applied (Fig 91). With those species that form the pupal cell in the inner bark, like the Black Hills beetle, the removal of the bark is sufficient to destroy the brood With species that pupate in the outer bark, however,

it is necessary either to burn the bark, or to expose it to the direct rays of a hot sun, in order to kill all of the brood (Figs 92 and 93)

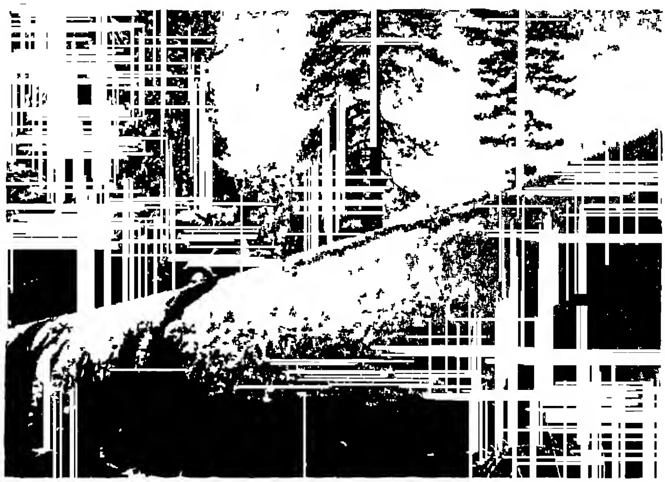


FIG 92 —Barking a tree infested with *Dendroctonus brevicomis* The first step i destroying the broods. (*F P Keen*)

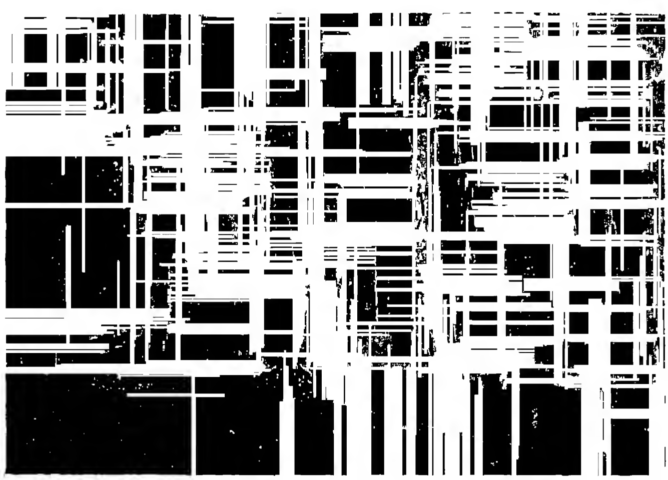


FIG 93 —Burning the bark removed from a tree infested with *Dendroctonus brevicomis* This final step is necessary in order to kill the insects in the pup cells within the bark (*F P Keen*)

The purpose of such control operations is to protect uninfeste timber from attack by reducing the abundance of the beetles t a point where natural agencies of control can hold them in checl

There is some indication from the work of the Bureau of Entomology, U. S Department of Agriculture, that uninterrupted logging operations, which provide a continuous supply of fresh logs to serve as traps for the beetles, may prove a satisfactory means of control for the Black Hills beetle. The role of parasites and predators is undoubtedly important in holding all Dendroctonus beetles in check, but so little is known about the exact part they play that they cannot be used in control work The application, therefore, of some of the mechanical methods mentioned above, must be depended upon primarily for the control of these insects. In accessible regions, where it is possible to cut and utilize infested trees, control of these insects may be accomplished almost without expense. In less accessible regions, the trees cut are usually a complete loss, because they will be decayed beyond a state of usefulness before logging operations will reach them In such instances, the usual custom is to pile and burn the infested trees that are cut Even though the timber treated is a complete loss, if the control operations prevent the spread of an outbreak and the resultant death of large areas of valuable timber, then a large expenditure is justifiable.

Questions on Literature

1 What species of Dendroctonus beetles are of greatest economic importance in the southeastern part of the United States, in the northeastern part, in the Rocky Mountain region, in the Southwestern States, and on the Pacific coast?

2 Which of the important species pupate in the bark and which pupate in the cambium region?

3 How do the tunnels of the important species of these beetles vary?

4 What other species of the genus Dendroctonus is very similar in appearance and habits to the Black Hills beetle?

5 What relation sometimes exists between outbreaks of defoliators and outbreaks of Dendroctonus beetles?

6 In what kind of forests are Dendroctonus outbreaks most common?

7 Is the spruce-destroying beetle an important factor in second-growth spruce forests? Why?

8 Describe the method of conducting an extensive beetle-control operation

The Pine Bark-beetle.—For a representative of another important group of bark beetles the pine bark-beetle, *Ips pini*, has been selected This is an extremely common species throughout the eastern half of the United States and Canada It is normally secondary although it may at times become primary.

The life history of the pine bark-beetle is very similar to of other species of the genus. The adults of this bark b are small, black beetles about ⅛ inch in length. As is the with all the members of the genus, the caudal portion o elytra, called the "declevity," is concave and bordered on side with spines This gives the beetle the appearance of ha the rear end of the body cut off sharply The beetles at freshly cut or unhealthy pines and, to a lesser extent, sp The male excavates a chamber in the inner bark, termec "nuptial chamber" Radiating out from this central chambe cut several mother galleries, each occupied by one female

FIG 94 —Galleries of the pine bark-beetle, *Ips pini*

94). The females, in cutting their galleries, push the frass into the nuptial chamber and the male relays it to the ou When the nuptial chamber becomes clogged, the females work until it is cleared, or in case of the death of the male, cease work entirely. As the mother galleries are exte eggs are deposited along the sides in niches These hatch the larvæ work out in the cambium at right angles to the m gallery. When development is completed, a pupal cell is fo at the end of each larval mine Here the pupal stage is pa The young adults feed for a short time in the inner bark and emerge to seek fresh material in which to establish a new ge tion In the North there is but one generation of this sp during a single season, but in the South there may be as ma three, and possibly more, because of the longer and warmer se

Control of the pine bark-beetle, and of other species of the genus, is usually unnecessary but occasionally, under some circumstances, they may be sufficiently injurious to require protective measures. For instance, during the recent years of excessive drought in the Southeastern States, much timber has been killed by these beetles. In other instances, where logging is carried on periodically and not continuously, beetles of this genus, and other bark beetles that normally breed in slash, may become temporarily primary and may kill some living timber, particularly seedlings and saplings.

Because of the danger that secondary insects breeding in slash may become temporarily primary, it is always desirable to carry on logging operations at an approximately uniform rate, and on adjacent areas, so that the beetles from the slash on one cutting area may be absorbed in the fresh slash on the adjacent area If this system is followed, there is little danger that slash insects will be an important factor in most forests. Where intermittent or scattered operations are necessary, however, a certain amount of loss must be expected, unless the slash is cared for in such a way as to reduce the abundance of slash insects. The usual methods of slash burning do not accomplish this end, because only the small portions of the waste material are burned The larger pieces, like broken or culled logs and stumps, offer the best places for the breeding of potentially injurious species of insects. Therefore, it is these parts that should be cared for, either by barking them or by piling over them the finer slash.

The pine bark-beetle is one of the insects that often causes the loosening of bark on rustic buildings Rustic material may be protected from this kind of injury either by careful sun curing, or by treating the bark with some repellant like creosote or carbolineum, before it is used for either buildings or furniture

Questions on Literature

1 What are some of the common bark beetles that attack the following trees hickory, ash, balsam fir, white spruce, hemlock, white cedar, cypress, larch, and douglas fir?

2 What are some of the species of the genus Ips that are important in the West, in the South?

3 What factors usually determine whether an attack of the pine bark-beetle will be located high in a tree or near the ground?

4 What are some of the natural enemies of the pine bark-beetle?

5. How long do the adult pine bark-beetles live?

CHAPTER XIII

CAMBIUM-WOOD INSECTS

The last group of meristem insects are those that attack both cambium and wood They are commonly called cambium-wood insects For the most part, these insects are pests of dying trees and freshly cut logs. In some cases, however, they attack living trees

PESTS OF LIVING TREES

Some of the outstanding examples of cambium-wood insects that attack living trees are the locust borer, the aspen borer, the carpenter moth, the basswood borer, the willow curculio, and the leopard moth Space permits of a discussion of only the first three of these species Information on other species may be secured by consulting the reading references given in the general bibliography.

All of the insects of this group work in the cambium for a time after the larvæ hatch and later penetrate into the wood Their work in the meristem is usually of comparatively short duration and is generally not sufficiently extensive to result directly in the death of the trees As a result of this, the chief injury caused by the activities of the insects of this group is a reduction in quality of lumber, or the mechanical weakening of standing trees, or a combination of weakening and reduction in grade. In addition to these direct effects, the cambium-wood insects open the way for fungous infection and thus materially hasten decay

The Locust Borer.—One of the best known examples of cambium-wood insects that attack living trees is the locust borer, *Cyllene robiniæ*, a member of family Cerambycidæ At one time the black locust in eastern United States was considered one of the best trees for posts, poles, and railroad ties because of its rapid growth and the durability of locust wood Many plantations of this species were set out in Pennsylvania and in the Ohio and Mississippi valleys Today, a large proportion of these plantations have been abandoned as valueless because of the

ravages of the locust borer, and even though the control of this insect is economically possible, the black locust is held in low repute as a result of early disappointments.

The adults of the locust borer are beautiful black beetles, ½ to ¾ inch in length, with narrow yellow cross-bands on the elytra (Fig 95) The beetles emerge in late summer and autumn. They deposit their white eggs in clusters of 5 or 6, in cracks and crevices, in the rough bark of black locust trees. Young trees under 1½ to 2 inches in diameter, and older trees over 5 to 6 inches in diameter, appear to be comparatively unsusceptible to attack, although if a tree is once infested it remains subject to infestation regardless of size. Thickness and surface character of the bark appear to be the factors that determine the susceptibility of the tree to attack The bark must be sufficiently old to be rough, but must not be so thick that the young larvæ cannot bore through it. This limitation of attack to certain specific age classes aids greatly in formulating plans for the control of this insect

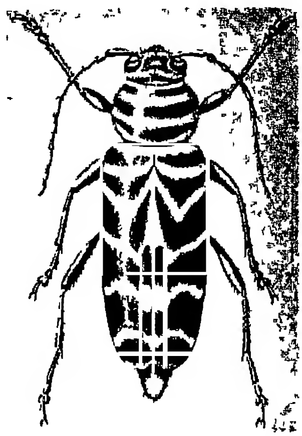


FIG. 95—Adult of the locust borer, *Cyllene robiniæ*, enlarged about one-third (*Bureau of Entomology, U S Dept. Agr*)

In a short time after they are deposited the eggs hatch, whereupon the young larvæ cut their way through the bark to the cambium. Here they feed until cold weather forces them into hibernation. The winter is passed in the larval tunnels. In the spring the larvæ continue their work in the cambium for a short time before entering the wood. Examination of infested trees will readily disclose whether the larvæ have entered the wood, or whether they are still in the cambium, because while they are working in the cambium they cast out of openings, through the bark, a brown-colored frass, whereas, after they enter the wood, they push from their burrows a yellowish colored frass. Throughout the life of the larvæ an opening from their burrows to the outside is maintained, through which the frass is ejected (Fig. 96) For a time, the entrance hole serves this purpose but later, as convenience demands, other passages are cut to the outside. The

larvæ, after completing their growth in late July and August, excavate cells in the wood in which they transform to the pupal stage, and later, in the same season, to the adult. Thus the life cycle is completed in one year

The control of the locust borer may be accomplished in several ways In forest plantations, Craighead has shown that silvicultural methods may be applied The beetles are sun-loving

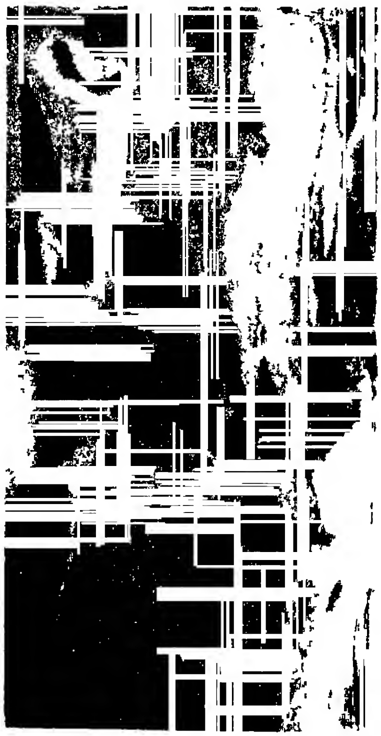


Fig 96—Tunnels of the locust borer, *Cyllene robiniæ*, in black-locust wood

creatures that delight to bask in the warm sunlight For this reason they congregate upon exposed parts of trees Because of this habit, trees growing in such a way that the trunks are shaded are immune from attack Even in localities where the pest is extremely abundant, dense stands are free from injury If borer injury is to be avoided, therefore, either the locust should be planted close enough together so that before the trees reach 1½ inches in diameter the crowns will meet and form a closed

stand, or else the locust should be planted in mixture with other trees or shrubs Craighead has also shown that comparatively isolated trees may be protected by a surrounding growth of shrubbery or by vines climbing on the trunks. Especial care should be used to keep fires out of locust plantations, not only because of injury to the trees but also because of its effect in killing the underbrush. Likewise, grazing in locust plantations should be avoided for the same reason.

In old plantations of locust that are heavily infested, the best course of procedure is to cut and destroy the badly injured trees and allow the root suckers to replace them Where this course is followed a dense growth of trees that will be practically free of injury by the borer will almost certainly be obtained.

The protection of shade trees is a much more expensive and difficult problem It can be accomplished, however, in several ways By allowing vines to climb over the trees, protection from the locust borer may be effectively accomplished. Spraying the trees with an arsenical wash of sodium arsenite in mixture with a miscible oil has proved effective. In using this mixture, one pound of sodium arsenite is dissolved in twenty gallons of water, to which one gallon of miscible oil is then added. This mixture should be sprayed on the trunks and large branches of the infested trees in the spring at the time the new growth is starting This spray is said to kill the young larvæ by penetrating into the tunnels They are probably killed by a double action: the oil acting as a contact poison and the arsenic as a stomach poison. Another method that is effective, though tedious, is to inject carbon bisulphide into the burrows of the insect. After injection the opening should be closed with mud, or grafting wax, to hold in the poisonous fumes Because of labor cost, this method is suitable for use only on valuable individual trees

Questions on Literature

1 Is the locust borer a native or an introduced pest? What is the evidence?

2 In what parts of the range of the black locust is the borer most abundant and injurious?

3 What trees and shrubs would you expect to find growing naturally with black locust?

4 At what age may black locust be expected to reach a diameter of 1½ inches? Six inches? Merchantable size?

5 Why was not the locust borer an important pest in the early days of settlement in the Ohio valley?

The Aspen Borer.—Another important cambium-wood beetle is the aspen or poplar borer, *Saperda calcarata* It is distributed throughout the United States and Canada wherever its host trees are found. This insect is injurious to forest trees both directly and indirectly. Directly it reduces the value of the trees

FIG 97—Tunnels cut in solid wood by the aspen borer, *Saperda calcarata* The curved tunnels in the upper part of the picture are pupal cells and emergence tunnels. (*Bureau of Entomology, U. S. Dept Agr*)

it attacks by cutting large tunnels in the wood (Fig 97). These tunnels may be so numerous in a heavily infested tree that the trunk will be much weakened, and the tree will be very easily broken off by high winds Occasionally, when the beetles are extremely numerous, a few trees may be killed as a result of

attack by this insect but, generally, the aspen borer is not a tree killer

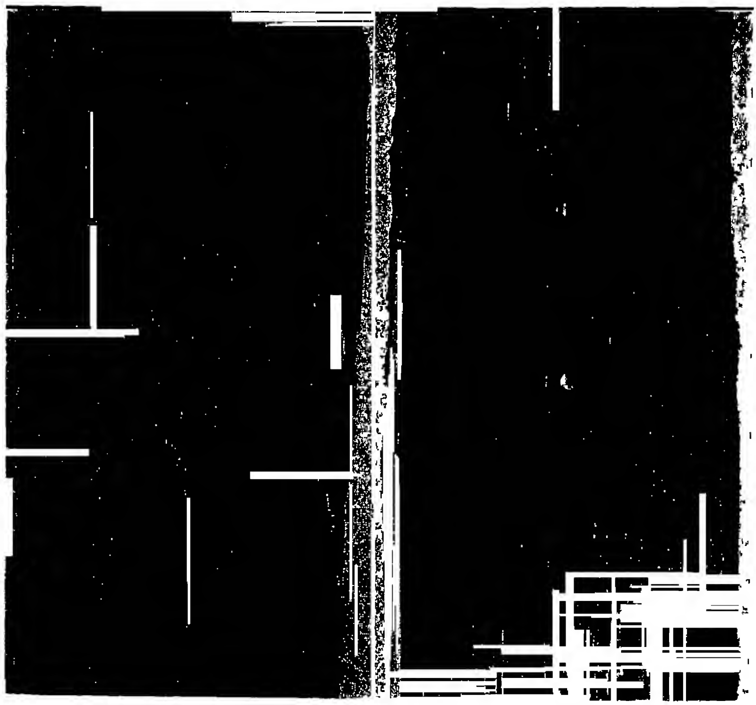
This beetle does, perhaps, even more important economic damage by its indirect effects than by its direct injury. Other injurious insects are attracted to trees that have been attacked by the aspen borer For instance, several Buprestidæ, for example, *Dicerca prolongata* (Fig 98) and *Pœcilonota cyanipes*, often deposit their eggs in the old egg scars of the aspen borer. The carpenter moth, *Prionoxystis robiniæ*, also finds that the scars made by the aspen borer offer desirable locations for oviposition Thus this beetle may be the indirect cause of other insect injury Certain other habits of the aspen borer are conducive to another type of secondary injury This insect keeps its tunnels com-

Fig 98 —An adult beetle of *Dicerca prolongata*, resting on a log

paratively free of frass by pushing this waste material out of openings through the bark. These open tunnels offer a ready means of access deep into the wood for the inoculum of wood-rotting fungi. *Fomes ignearius*, an important heart-rot that causes a large proportion of the defects found in aspen and poplar, frequently gains entrance through these openings In some regions, it has been shown that a large proportion of heart-rot infections have arisen from insect tunnels Thus the aspen borer and the carpenter moth are indirectly responsible for a great deal of damage which is not ordinarily charged to them.

The adult aspen beetles are rather large, often over 1 inch in length Their color is grey, with yellow markings They emerge from their pupal cells in late July and August The female beetles lay their eggs in slits that they gnaw in the bark (Fig 99) The period of incubation is long, 20 to 25 days being required for its completion The larvæ, as soon as they hatch, tunnel through the bark into the cambium where they feed until

overtaken by cold weather. The following spring they enter the wood where they spend the remainder of their developmental period tunneling through the wood (Fig 100) In the autumn, when full grown, they hollow out a pupal cell in the sapwood. This cell is blocked off by a plug of shredded wood from the tunnel in which the insect has previously been living. The



A B

FIG 99 —The egg slit and eggs of the aspen borer A shows a view of the egg slit as it appears on the surface of the bark B shows the eggs in place in the inner bark (*Bureau of Entomology, U. S Dept Agr*)

winter is passed in the prepupal stage within the pupal cell Early the following summer the larvæ transform to the pupal stage, after 25 to 30 days in that stage, they transform to the adult, cut their way to the surface, and emerge Thus the normal developmental period is 2 full years. In Colorado, however, at elevations ranging from 6,000 to 9,000 feet, this species requires 3 full years to complete its life cycle In warmer climates, on the

other hand, it is probable that a developmental period shorter than the normal is possible

Because of the fact that infested trees are more attractive to the aspen borer than those that are uninfested, the beetles have a tendency to concentrate upon certain trees These favorites become very heavily infested and are sometimes called "brood trees." By cutting and destroying these brood trees in a forest, the possible injury by this pest may be greatly reduced After being cut, the brood trees should either be burned before the beetles emerge, or be split and ricked up in open piles in such a way that rapid drying and the heat of the sun will kill the beetles in the wood

FIG 100 —A larva of the aspen borer, *Saperda calcarata* (*Bureau of Entomology, U S Dept of Agr*)

It has been repeatedly observed that slowly-growing trees are always much more susceptible to borer injury than are rapidly-growing trees This is doubtless due to the greater ability of the fast-growing trees to overgrow wounds and scars Such trees have a covering of smooth, healthy bark and are not so attractive as the slower-growing trees Control measures for this insect are usually only necessary on the poorer quality sites

The borer when working in individual trees may be controlled by painting the egg scars with carbolineum This work should be done in the autumn after oviposition has been completed Both the eggs and young larvæ will be killed by this treatment

Questions on Literature

1 What other cerambycids are injurious to poplars?
2 In what regions is the aspen borer most serious?
3 How may the males of the aspen borer be distinguished from the females?
4 Does this borer ever attack dead trees? Why?
5 Does this insect ever attack green logs or pulpwood?

The Carpenter Moth.—The carpenter moth, *Prionoxystus robiniæ*, is one of the common cambium-wood insects that may

well be cited as an example of the lepidopterous members of this group It is distributed generally throughout the United States and at least the southern part of Canada This insect was first described as a pest of black locust, hence its specific name, but it also feeds upon a variety of hardwood species. Some of the trees that are frequently attacked by this insect are the oaks, elms, and poplars

The carpenter worm seldom kills trees Most of its work is in the solid wood, and only in the early stages of development are the larvæ cambium eaters. Although this insect does not kill trees, it is, nevertheless, a primary pest and most of its damage is done to living trees

The adults are large gray moths with a wing spread of about 2½ inches They emerge in early summer and deposit their eggs on the bark of a host tree. Wounds and scars on the trunk or larger branches provide the most attractive places for oviposition. The larvæ, which hatch in a couple of weeks from these eggs, bore into the cambium where they excavate shallow galleries. After a brief period they penetrate into the sapwood and heartwood where they spend the rest of their immature life (Fig 101) The larvæ are typical caterpillars in form and pinkish white in color They cut long winding galleries in the wood. These galleries are kept clear of frass so that the larvæ can pass freely back and forth in them. In order to secure free passages the borings are pushed out through holes in the bark These holes provide an easy entrance for wood rots, consequently, these organisms are frequently associated with the work of the carpenter moth

The length of the larval period has not been definitely determined, but in all probability it varies with differences in climate, as is the case with most other insects In any case, however, several years are usually required for its completion In California the life cycle requires 3 or possibly 4 years In New York state the life cycle is said to be probably 3 years At the end of the larval period, a pupal cell is formed in the wood near the surface and, before pupation, a hole is cut almost through the bark. The tunnel behind the pupal cell is plugged with shredded wood The larvæ then transform to the pupal stage and, later, the moths emerge

Almost all the investigations concerning this insect have been confined to their activities on shade trees, and as a result,

although in some instances it is an important forest pest, no control under forest conditions has been developed In shade trees, the insect can be controlled by injecting carbon bisulphide into the tunnels. Caging the trunk and larger branches of

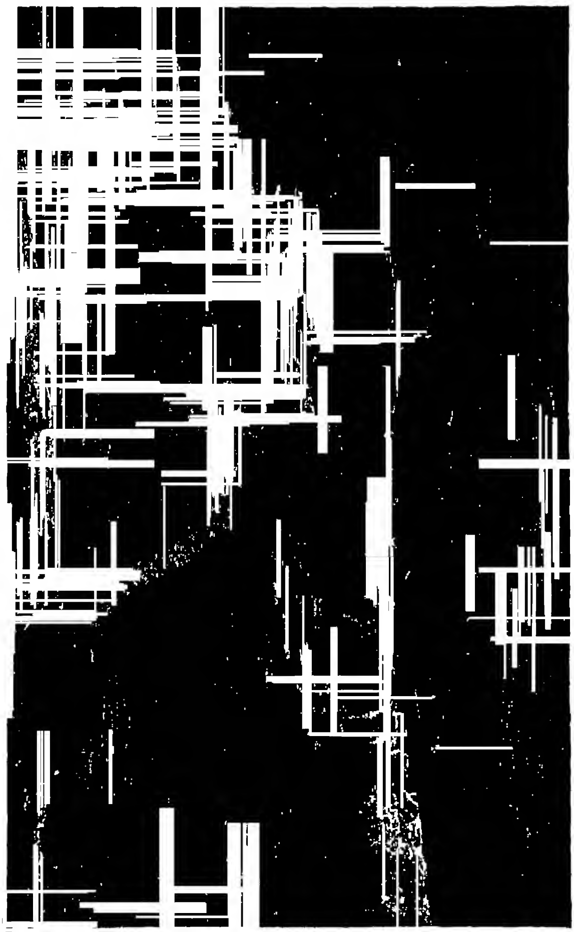


FIG 101—Larvæ and work of the carpenter worm, *Prionoxystus robiniæ*, in an oak tree (*Entomological Branch, Can. Dept. Agr*)

heavily infested trees to prevent reinfestation has been suggested. If the moths that emerge within the cage are killed daily, there will be no infestation from within, and the cage will effectively exclude moths from without. The cages should be kept on the

trees throughout the late spring and early summer when the moths are in flight. After the flight season is over, the cage may be removed and stored away until the next season After a tree has been freed of infestation, caging should be continued for several years until the wounds made by the borers have been completely healed Otherwise reinfestation will be certain to occur, in as much as injured trees are very attractive to the moths After the bark has completely grown over the wounds, the tree will be comparatively resistant to infestation. (Burke, 1921.)

Questions on Literature

1 What other species of carpenter moths are injurious to forest and shade trees?

2 What are some of the ways in which these insects may injure trees indirectly?

3 In what regions are these pests most abundant?

4 How soon after emergence do the moths begin oviposition?

5 How may the larvæ of wood-boring Lepidoptera be distinguished from coleopterous wood-boring larvæ?

PESTS OF DYING TREES AND LOGS

Representatives of those species that attack only dying trees or freshly cut logs, will now be considered Insects of this group are important because of the loss which they cause, in both saw-logs and pulpwood, by reducing the grade of the former and the volume of the latter, not to mention the indirect injury for which they are responsible, through aiding infection by wood-rotting fungi Craighead estimates that the loss in grade, due to the activities of this class of insects, amounts to about 5 per cent of the value of the annual cut The most important of these insects belong to the Buprestidæ of the Coleoptera or the Cerambycidæ

The Flat-headed Borer.—One of the many buprestids that feed on both cambium and wood is the flat-headed borer, *Chrysobothris femorata* This insect attacks numerous species of forest trees and also a great variety of orchard trees (Fig 102). Some of its hosts other than fruit trees are walnut, pecan, hickory, poplar, willow, beech, oak, elm, hackberry, sycamore, mountain ash, hawthorn, redbud, maple, horse chestnut, basswood, persimmon, and box elder Its hosts are so varied that it can almost be regarded as a general feeder on hardwoods Because of its importance as a pest of apple trees, this insect is often called

the flat-headed apple-tree borer. Because it is a pest of orchards as well as a forest pest, it has received more attention from entomologists than if its activities had been confined to forest trees alone. As a result, its habits are well known, and it will serve well as an illustration of the cambium-wood buprestids.

The flat-headed borer lies in the middle ground between the primary and secondary insects It apparently cannot attack successfully a vigorous, healthy tree but is able to attack trees

FIG 102 —Adults and larvæ of the flat-headed borer, *Chrysobothris femorata* (*Bureau of Entomology, U. S Dept of Agr*)

that are slightly on the decline. The adult females are attracted for oviposition not only to the subnormal trees but also to healthy trees in sunny locations They very frequently oviposit freely upon such trees. The eggs hatch and the young larvæ bore into the bark, but they do not enter the cambium while the tree is in a thrifty condition. If, however, such trees should, by chance, decline in health, the larvæ will promptly penetrate into the cambium and kill the tree If, on the other hand, the tree remains in good health, the young larvæ will remain in the bark for at least one year before they succumb to starvation This habit has been observed in other species of the same genus,

for example *Chrysobothris dentipes*, a flat-headed borer of pine. When bark-infested trees are cut, the larvæ are then able to attack the cambium and later the sapwood; thus they are able to complete their normal development in the logs.

The adults of the flat-headed borer are short, broad, flat, beetles about ½ inch long. In color they vary from dark brown to black on the top, with grayish spots and bands, while the ventral side and the legs are bronze. They emerge from their pupal cells in early spring and are then on the wing for about one month. The beetles are active only on warm, sunny days. At other times they remain quiescent, hidden away beneath bark scales or in other suitable places. In warm weather they are very active, flying and running about Experiments have shown that insects of this genus are very resistant to heat and can endure a temperature as high as 52° C without being killed The larvæ, like the adults, are heat resistant and are able to live on the upper side of logs lying in the sun, where no other insect life can exist

The female beetles deposit their eggs in crevices in the bark of the host trees. These eggs are pale yellow, flattened, and about 1/20 inch in diameter The young larva, after an incubation period of 15 to 20 days, bores through the under side of the egg and into the bark. So far as is known, this habit is true of all buprestids.

The thoracic region of these larvæ is greatly enlarged transversely and flattened dorso-ventrally The head is invaginated into this enlarged thorax so that only the mouth parts protrude On casual inspection, the thorax appears to be the head of the grub, thus the name flat-headed borer The larvæ are helpless when removed from their burrow Unless they have convenient surfaces against which they can expand the enlarged thorax, they are unable to move; therefore it is only in a tunnel that fits their bodies perfectly that they can move about. Thus, if a larva should cut through some portion of the egg that was not in contact with the bark, it would be helpless and unable to progress further

If on boring through the bark the larvæ find conditions are favorable, they will construct broad feeding tunnels in the cambium and outer sapwood. They grow rapidly and in late summer are ready to bore into the solid sapwood. Here they form their pupal cells in which they pass the winter. In the South the pupal

cell is sometimes formed between the bark and wood, but this condition has never been observed in the North. The winter is passed in the larval stage within the pupal cell and pupation takes place early in the following spring.

Thrifty trees are not susceptible to this type of borer injury, this species, therefore, is only a pest of overmature, decrepit, or dying forest trees The greatest loss occasioned, by this and other insects of the genus, is in green forest products and not in standing timber (Fig 103) The tunnels cut in the sapwood reduce the grade of the most valuable part of a log, for it is in the

FIG 103—The work of *Chrysobothris dentipes* in norway pine This species works in a manner very similar to that of *C femorata*

periferal portions of a log that the highest-grade, clear lumber is produced Logs may be infested either before they are cut, if the trees are overmature, or after they are cut, if the trees are left lying in the woods during the flight season of the beetles. Injury to logs may be prevented by prompt utilization, by floating them in water, by keeping them wet through use of the sprinkler system, or, in warm sunny climates, by the method of sun curing previously described In the North, logs that must be left in the woods over the growing season may be covered with brush. If they were not infested prior to shading, they will not be attacked by this borer; if they had been previously infested, the temperature within the logs will be so much lowered by shading that the rate of larval development will be materially reduced.

Questions on Literature

1. What other species of the genus Chrysobothris are important forest insects?
2. What factors determine the effectiveness of sun curing of logs in controlling flat-headed borers?
3. What parasites attack the flat-headed borer? How effective are they?
4. What predators help to control this borer?
5. What influence does the presence of slash in an area have upon the abundance of these borers in that area?

The Small Pine-sawyer.—Numbers of cambium insects refuse to attack standing trees until they have been severely injured or killed by some other agency. Of these the small pine-sawyer, *Monochamus scutellatus*, is a good example This secondary insect is one of the most common wood-boring insects in the

Fig 104 —A small pine-sawyer, *Monochamus scutellatus*, emerging from a white-pine log

coniferous forests of the Northeast It infests and reduces the value of freshly cut logs, and of trees that have been severely injured or killed by fire, or other insects This insect is so abundant, in most localities, that practically every log or newly killed tree that is left in the woods over the summer is almost certain to be infested

The habits and life history of this species are very similar to those of other closely related species of Monochamus The adult insects are somewhat elongate, cylindrical, black beetles about 1 inch long with very long filiform antennae (Fig 104) The antennæ of the male are twice as long as the body, whereas those of the female are only slightly longer than the body The adult beetles emerge in spring and early summer During the flight period they feed upon the green bark of pine twigs Sometimes, when the beetles are abundant, numerous pine tips may be girdled and killed as a result of this feeding activity After feeding for a brief period, the beetles deposit their eggs in slits

which they cut, in the bark of logs and recently killed trees, with their mandibles Oviposition continues throughout the summer season but it usually reaches its height before midsummer.

The larvæ hatch from the eggs and tunnel at first in the cambium region. They are legless, cylindrical, white grubs with powerful mandibles. They excavate broad, shallow galleries in the cambium, but as they increase in size their cambial galleries not only include, in their depth, the green tissues of the inner bark but also cut into the surface of the wood (Fig 105). Later the larvæ penetrate into the sapwood and sometimes into the heartwood. When growth is completed, the larvæ cut a pupal cell in the sapwood and transform to the pupal stage. The length of the developmental period varies greatly Under favorable conditions of temperature and moisture, a single year is sufficient, but, under less favorable conditions, the life cycle may require 3 years and possibly longer. The larvæ of this species, like those of the aspen borer and the carpenter moth, always keep at least a part of their tunnels clear of frass and chips This material is cast out through openings in the bark. Like the other insects just mentioned, the pine sawyer maintains ideal conditions for the infection of the log with wood rots. These organisms are usually associated with Monochamus work.

FIG 105 —The broad, subcortical gallery of the small pine-sawyer, *Monochamus scutellatus* These galleries are cut during the early life of the larvæ before they enter the wood

This insect tunnels primarily in the periferal layer of a tree or log It is in this layer that the most valuable high-grade wood occurs. Thus, in clear logs the insect may reduce the grade of lumber, sawed from infested parts, from a select grade to a No. 3 grade, this means a reduction in the retail value of the best lumber from $50 to $100 per thousand feet at present

prices Furthermore, by reducing the grade of high-class materials, the insect increases the quantity of the already too abundant lower grades, thus adding to the problem of lumber sale and distribution

Control of the small pine-sawyer may be accomplished in a variety of ways Fire-killed trees should be promptly utilized or cut and kept wet with water. Prompt utilization is the best way to handle the borer problem Water storage of freshly cut material, either by emponding or by sprinkling, is the next best solution. If neither of these methods is feasible, barking will prevent infestation by destroying the necessary green food for the young larvæ. If the insects have penetrated into the wood, however, barking is useless The cost of barking varies with conditions of labor and timber, but, in good-sized eastern white and red pine, the average cost was approximately 10 cents per log, under conditions existing in 1924. Only high-grade logs should be barked. The cost of barking a low-grade, knotty log is as much or possibly more than the cost of barking a clear log, while the reduction in grade in the low-grade log is practically a negligible quantity On the other hand the saving in grade resulting from barking a clear log attacked by the sawyer will many times over pay for the cost of barking. One serious objection to barking saw logs is the fact that barked timber has a tendency to check badly, but such injury is infinitesimal as compared with that caused by the borers.

Where no other method of control can be used, experiments indicate that a heavy shade of brush, piled over logs left in the woods during the summer, will afford some protection from this insect This cannot be recommended if other methods can be used, because of the inferior quality of protection afforded by this method.

Questions on Literature

1. What is the most important species of Monochamus in the Southeast? The Southwest? The Pacific Northwest?
2. What species of Monochamus are tree killers?
3. What are the most important cambium-wood insects of ash, poplar, oak, elm, maple, cedar, douglas fir, and cypress?
4. Under what conditions would one expect the maximum injury by cambium-wood insects to logs?
5. Under what conditions might Monochamus be injurious to sawed lumber?

CHAPTER XIV

WOOD DESTROYERS

Although most tree insects require green meristem tissues for food, during at least a part of the developmental period, there is an important group which is able to develop from egg to adult upon wood alone. The insects of this group are chiefly secondary pests attacking forest products, although some of them may at times attack and injure standing green timber Some of the wood insects require green wood, for example, the horntails, others, like the ambrosia beetles, work in either green or moist wood. The termites and the carpenter ants are not quite so exacting in their moisture requirements for they will tunnel into wood that is moderately dry The powder-post beetles, on the other hand, cannot work in wood unless it be thoroughly air dried.

The insects that attack and injure wood may be divided, for convenience of discussion, into several groups as follows·

1 Insects of moist wood
   a Unseasoned-wood insects
   b Moist dead-wood insects
2 Insects of dry wood

Various wood-destroying insects will be taken up under these headings, but it must be kept clearly in mind that this grouping is purely arbitrary, and that moisture content is a relative matter, hence, there are species that might be put in either of the two groups This absence of a sharp division is especially evident between insects attacking moist dead wood and those attacking dry wood

The preceding paragraphs seem to imply that all wood destroyers are insects This is not, however, the case. There are a few other groups of animals that are wood borers The most important of these are the marine wood borers Because their activities are very similar to wood-destroying insects, these animals will be included in this chapter. Since they attack

only moist dead wood, they will be discussed in a section following the Moist Dead-wood Insects

UNSEASONED-WOOD INSECTS

The unseasoned-wood insects are those that attack the wood of dying trees, or of trees that have been recently killed or freshly cut After the wood has been dead or cut for a season or more, it is no longer attractive to these insects. This unattractiveness of old wood for the green-wood insects is sometimes due to changes in the moisture conditions which usually follow cutting, but even where moisture conditions apparently continue favorable, the wood after a time becomes unattractive. This is apparently due to changed physical and chemical conditions within the wood What these changes are has never been definitely determined. There is some indication that unseasoned-wood insects may be attracted to freshly killed or cut wood by products of fermentation that disappear as the wood seasons, or as organisms of decay gain a predominant position in the wood. The fact that ambrosia beetles are not attracted to wood that has been cut for more than a year, even though moisture conditions are favorable, but are attracted to and attack wine casks that contain wine in storage, suggests that, perhaps, the presence of an alcohol may determine the places chosen by the beetles for their activities Whatever the reason for this attraction, the fact remains that insects of this group are only attracted to unseasoned wood or to wood which, for some reason, simulates conditions found in unseasoned wood

The Ambrosia Beetles.—Ambrosia beetles, or pinhole borers, comprise an interesting and important group of unseasoned-wood insects, all members of which, with the exception of the genus Platypus, belong to the family Ipidæ. Although they belong to the same family as the bark beetles, their habits are very different. These borers are small, dark-colored insects, more or less cylindrical in form They live in moist or freshly cut wood into which they cut their tunnels. The entrances of these tunnels resemble those of the bark beetles, but, because they tunnel into the wood, the frass which they cast out is light colored instead of brown Although they bore into the wood, they are not wood eaters, instead, they feed upon a fungus growing on their tunnel walls. This fungus is always associated with the ambrosia beetles, each group of beetles having its own

specific fungus. Whenever a tree ceases to be suitable for the growth of this fungus, the beetles must leave. With them, adhering to their bodies, they unwittingly carry either the sticky spores or perhaps the mycillium. Having sought out a suitable, freshly-cut tree or stump they proceed to bore directly into the wood. For a short time they are without food, but soon the spores, which they have brought with them, germinate, giving rise to a new growth of ambrosia fungus.

This apparent cultivation of its food by an insect has caused many observers to ascribe a high degree of intelligence to these beetles. The facts, however, will not permit crediting too much intelligence to these interesting insects It is nothing more than a very interesting example of a symbiotic relationship between a fungus and an insect The beetle depends upon the fungus for food, and the fungus depends upon the insect for transportation from an old host to a new one.

The arrangement of tunnels varies greatly with different species of ambrosia beetles (Fig 106). Some species construct simple galleries in which the eggs, larvæ, pupæ, and adults are found living together; others construct compound tunnels with numerous branches, along the sides of which are constructed niches known as larval or pupal cradles With such species the eggs are deposited in these niches and also the larvæ develop and pass through the pupal stage in them These larvæ are fed by the adult beetles who insert plugs of the ambrosia fungus into the cradle entrances In the species where no cradles are formed by the adult, or where pupal cells similar in appearance to the cradles are formed by the active larvæ just previous to pupation, the larvæ shift for themselves, feeding upon the ambrosia fungi growing on the tunnel walls.

The ambrosia-beetle colonies are constantly faced with two problems The first is the selection of trees in which conditions are suitable for the growth of the fungus upon which they feed The other is to protect themselves against the growth of the fungus itself In the event that conditions for the growth of the fungus are not right the larvæ will starve, and the adults will be forced to seek other trees. If conditions are favorable for the fungus, but the beetles do not multiply rapidly enough to consume their food as fast as it grows, the rank growth of the fungus may block the tunnels, thus smothering the beetles in their food

There are numerous species of ambrosia beetles, most of them belonging to one of the following genera: (1) Platypus, (2) Anisandrus, (3) Xyleborus, (4) Gnathotricus, (5) Pterocyclon, (6) Trypodendron, (7) Xyloterinus. Some of them are confined

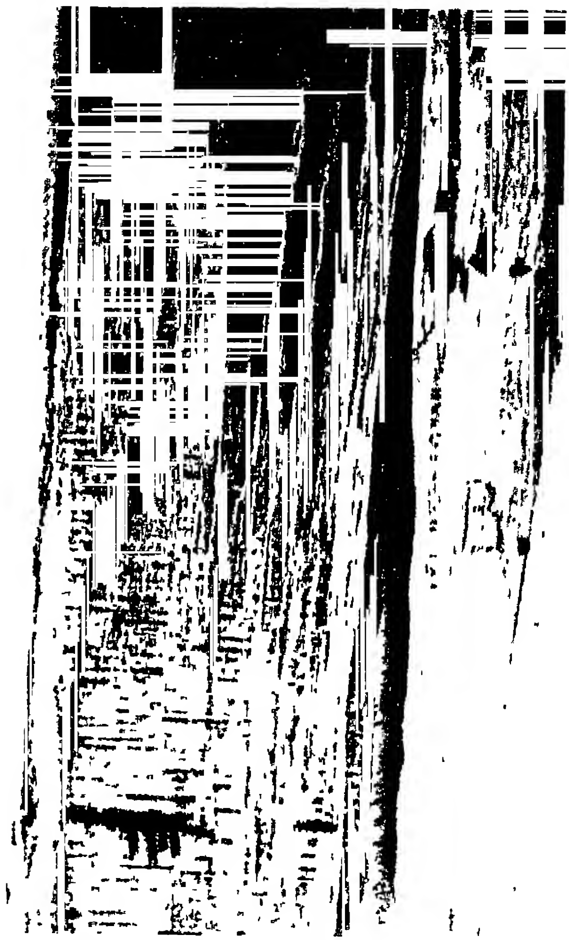


FIG 106—The galleries of an ambrosia beetle showing the walls stained black by the growth of fungus.

to a single species of tree, whereas others may be found in a number of species. It is probable that, in as much as the beetles do not eat the wood but simply use it as a place to construct their nests, the specificity of the beetles for certain trees is the

direct result of the specific requirements of their particular fungus

The injury, to logs and recently killed trees, by ambrosia beetles results in a decided loss in quality of the lumber and other products cut therefrom This type of injury is serious in lumber because of the resultant reduction in grade, but it is even of greater consequence in other classes of material, for example, stave bolts, and wood intended for wagon stock, or other special uses. With such materials, pinhole injury may render the product valueless

In certain cases, however, ambrosia-beetle tunnels cannot be considered as serious defects In oak flooring, for instance, present day style demands a few knots and a few "worm holes." These defects are said to lend character to a floor, and in some high class homes this one time low-grade flooring is now being used In fact, in some instances where a grade of flooring free of these defects is furnished, small holes are actually burned in the wood to imitate the tunnels of the ambrosia beetles In most cases, however, beetle tunnels constitute a defect that decidedly reduces the value of any forest product so injured.

Some of the greatest losses occasioned by these insects occur in the South An unusually good example of this is found in the cypress forests. It is customary to girdle these trees sometime previous to felling, so that they may dry out sufficiently to be floated out of the swamps in which they grow. Between the time of girdling and felling, the trees are often attacked and rendered almost useless by these beetles. Other Southern tree species are often severely injured before the logs can be manufactured. Throughout the South, where the growing season is long and the number of broods is great, the ambrosia beetles present an exceedingly serious problem They have spelled ruin to more than one logging venture (Fig. 107)

In the North, on the other hand, several factors tend to reduce the economic importance of these insects. The long winters make possible easy logging while the beetles are dormant, this eliminates most of the injury in the woods Furthermore, the custom of river driving the logs prevents later attack, in as much as logs floating in water are too moist to permit the growth of the ambrosia fungus.

The control of the ambrosia beetles is very difficult and entails in many instances considerable expense They can,

however, be held in check in several ways The prompt sawing of logs followed by kiln drying provides the best and most certain protective measure, but, unfortunately, the application of this method is frequently out of the question. In general, it may be said that rapid seasoning is an important aid in the control of these beetles This may be accomplished in large diameter

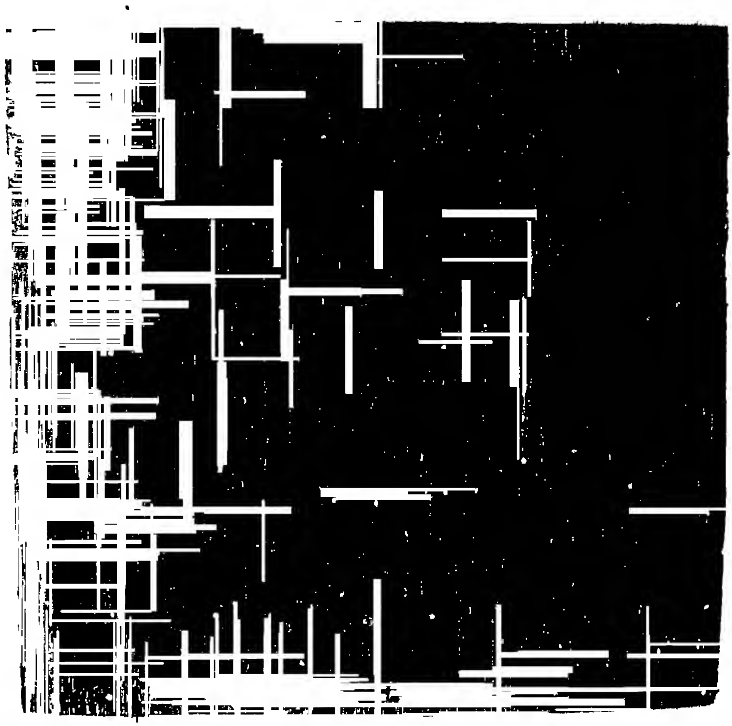


FIG 107—Injury to hickory caused by one of the ambrosia beetles, or pinhole borers, *Xyleborus xylographus* (*Bureau of Entomology, U S Dept Agr*)

stock by barking and piling the logs or bolts in open piles It should be borne in mind, however, that barking tends to increase checking. Wood of small diameter may be dried sufficiently by piling in loose piles without barking.

Where storage space and expense will permit, sun curing is an effective means of controlling these and other wood borers It has previously been shown that the subcortical temperature, on the upper side of logs exposed to full sunlight, often exceeds the

air temperature by thirty degrees or more, and frequently passes above the point fatal to insects By applying this principle, Craighead has shown that if logs are placed in the bright sun, and are turned every week or two, the insects attacking these logs will be destroyed before they have injured the wood. In controlling ambrosia beetles, however, the logs should be turned somewhat more frequently than this. By placing the logs on long, sloping skids, they may be turned with a minimum of effort.

In cases where girdling is necessary before trees can be felled, the girdling should be done in late fall, after the beetle flight is over, in order to reduce to the minimum the injury by ambrosia beetles. It has also been suggested that inferior trees may be used as trap trees for these insects, by girdling or felling them in early spring, when the beetles are in flight. According to this plan, the beetles will be attracted to these logs or girdled trees and may be destroyed by placing the logs or trees in water, or by burning them

One of the best and most effective methods of preventing attack by ambrosia beetles is by the water treatment. As with other insects, this may be accomplished in either of the two ways already discussed, namely, by sprinkling or by floating in water. By increasing the water content in either of these ways the beetles are effectively excluded The water treatment does not, however, give permanent immunity unless the logs are kept in water for a year or more

Ambrosia-beetle injury is not always confined to freshly cut or killed trees Sometimes ambrosia beetles will attack green lumber, particularly large dimension stock which dries slowly The danger of this may be greatly reduced by careful piling, so as to provide good circulation of air through and around the piles, thus encouraging rapid drying Absolute protection may be obtained by running susceptible materials through a dry kiln.

Questions on Literature

1 Which species of ambrosia beetles attack pine? Which attack birch?

2 Why is ambrosia-beetle injury in the South greater than in the North?

3 What are the limitations of sun curing as a control for ambrosia beetles?

4 What trees are attacked by members of the genus Platypus?

5 Where and by whom was the ambrosia studied and determined to be a fungus?

The Horntails.—Another important group of unseasoned-wood borers is the family Siricidæ of the order Hymenoptera Like the ambrosia beetles, these are green-wood borers and attack injured trees or recently cut logs They are very common insects and are responsible for greater damage to forest products than is usually ascribed to them Although many species are known to science, little detailed information concerning their life histories and habits is available. They will, therefore, be treated more briefly here than might otherwise be expected. Unlike the ambrosia beetle, the horntails are for the most part true wood-eating insects (*Xylophagous*). They work in the solid wood, maintain no opening to the outside, and are apparently not necessarily associated with any fungi One of the largest and best known members of this group is said to be an exception to the above rule in that it bores only into decaying wood This is the species known as the pigeon tremex, *Tremex columba*

The horntail adults may be described as thick-waisted wasp-like insects. They vary greatly in size; some of them are less than ½ inch in length, whereas some are 2 inches long. Black is the predominant color of the family but nearly all species are characterized by markings of yellow or orange. At the end of the abdomen the female bears a horn-like ovipositor from which the group name is derived.

The adults of most species fly in spring and early summer The females, by means of their long ovipositors, insert their eggs into the solid wood. This is no mean feat when the flexibility of the ovipositor and the solidity of the wood, into which it is inserted, are considered. Sometimes a female may get her ovipositor wedged into the wood so that she is unable to extricate herself. Such occurrences, however, are not as frequent as might be expected. The horntails are particularly abundant and especially injurious in fire-killed forests. The scorched trees appear to be particularly attractive to the adults. Trees killed by spring fires are much more susceptible to injury by these insects than are trees killed at other seasons of the year.

The horntail larvæ are white legless grubs (Fig. 108). They tunnel through the wood, cutting burrows just large enough for their bodies. The wood passes through their digestive tracts and is packed behind them as they advance. The length of the larval stage appears to be variable, even with the same species, and depends, apparently, upon conditions of temperature and

moisture. With most species the larval stage is completed in one or two seasons When growth is completed, the larvæ cut pupal chambers in the periferal layer of the sapwood. In logs

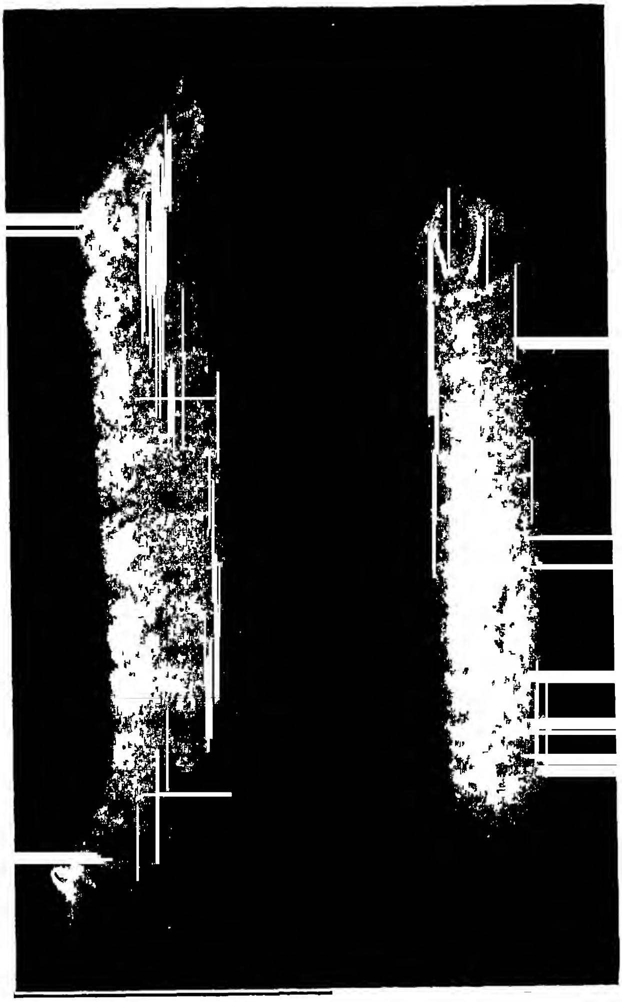


Fig 108 —Horntail larvæ from a douglas-fir log (*Bureau of Entomology, U S Dept of Agr.*)

the pupal cells are usually constructed on the upper side so that, although the larval work may be distributed throughout the log, the majority of the exit holes are usually on top.

Water treatment is the best way to prevent injury by these insects. In fact, it is about the only effective method to save logs except for the obvious one of prompt utilization. These borers may continue to work in green lumber sawed from infested logs Kiln drying gives good control in sawed materials The same result may be accomplished by raising the temperature of the wood above the point fatal to the insects, by dipping it in hot water.

MOIST DEAD-WOOD INSECTS

The insects that injure moist dead wood form another group of important pests of forest products. They attack wood that has been cut or dead for one year but is still, at least, partially moist as a result of contact with the ground or other moist material. Insects that work in moist dead wood are usually associated with fungi and bacteria These organisms apparently help the insects by converting the comparatively indigestible cellulose or the lignin into materials that are more easily digested by the insects Because of the micro-organisms present in it, moist dead wood provides more suitable food conditions for its insect inhabitants than the green wood of the freshly cut or newly killed tree An indirect proof of this is found in the fact that moist dead wood is attacked directly by many insects, whereas very few species can gain a living in the green wood, without either depending upon the cambium to carry them through the early stages of larval development, as the cambium-wood insects do, or by depending for their food upon symbiotic fungi, as do the ambrosia beetles The dietetic relationships of these organisms offer a fertile and almost virgin field for future investigations. Some of the wood borers, like the carpenter ants, do not obtain their food within the wood, but only use their tunnels in the log or tree for a sheltered base from which to conduct foraging expeditions and for a nursery for their young

The Carpenter Ant.—There are many insects which bore in moist dead wood One of these which is very widely distributed in the United States and Canada is the carpenter ant, *Camponotus pennsylvanicus*, or its variety *ferrugineus* The carpenter ants are large black ants, sometimes ½ inch or more in length, which build their nests in soft or decaying dead wood, and there rear their young well protected from the attack of enemies. They are social insects, living together in large colo-

nies. These ants do not have as many casts as do the termites which will be discussed later, nor are they so obviously polymorphic in character, but there is a distinct division of labor within the nests. Three casts are recognized: the kings and the queens which are the true males and females, and the workers, which are sexually undeveloped females. Although the workers are all alike in appearance, each has her own work to do. Like the honey bee, some of the workers care for the young, others care for the queen, while still others collect food

The life history of the carpenter ant is very interesting. In brief, it is as follows: In early summer the young males and females leave the nest. Being winged at that time, they fly out in all directions Sometimes the air may be filled with these flying ants that have emerged simultaneously from many nests. This is known as the swarming period, but unlike the bees, in swarming, the young males and females leave the nest at the same time, unattended by workers. It would be much better to call this the mating flight, for that is really what it is.

Shortly after mating, the males die while the young females may either be taken into old established colonies to replace a decrepit queen, or each may establish a new colony. In the latter case, the young queen seeks out a small cavity in a tree or piece of timber and there makes up her brood cell by completely enclosing the cavity, leaving no exit or entrance. She then breaks off her wings, for they are no longer of any use to her After sealing herself in, she does not feed again until her first brood of young is mature (Wheeler, 1910) After depositing a few eggs in the brood cell, she hatches larvæ which are fed upon a material secreted from her mouth. The young then complete their larval development, spin their cocoons, pupate, and emerge as adults, without any other food than that furnished by the mother from her own body The ants of the first brood are workers of very small size As soon as they are mature they take over the work of the nest They cut approximately parallel, concentric galleries running longitudinally through the wood to accommodate the enlarging colony and bring the organic food, on which they live, into the nest through openings cut to the outside, sometimes called "windows" The young workers feed the queen and care for the eggs that she lays and the larvæ that hatch from these eggs They feed the young, after the first brood, upon secretions from their mouths The nurses carry both the larvæ

and pupæ from place to place in the nest, in an effort to keep them under the most favorable conditions; also, when the young adults are fully developed, they are assisted from the cocoon and treated with the greatest consideration. As the colony grows, more galleries are cut in order to enlarge the nest.

Carpenter ants may build their nests in a great variety of places They may attack the dead heartwood of living trees, or they may hollow out logs, house timbers, or almost any wood materials. It has been stated, frequently, that these insects only attack decaying wood. This is not entirely true, although the original attack is usually in a decayed spot In trees having

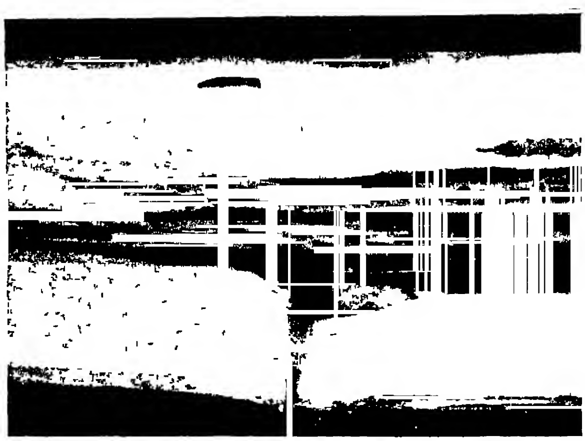


FIG 109.—A nest of the carpenter ant, *Camponotus pennsylvanicus*, in a white-cedar log

hard wood, the work is confined to decayed wood but in trees having soft wood, like cedar, the nests are often constructed in solid wood (Fig. 109). The only requirements are that the wood be soft and moist.

The carpenter ant does its greatest injury in house timbers and in standing trees of soft wood. In northern white cedar, *Thuja occidentalis*, the injury by these insects is very common; in fact, it is one of the most frequent defects of cedar In some locations, at least 20 per cent of the trees that are cut show ant injury. The nests are usually built comparatively near the base of the trees, the highest being not much more than eight or ten feet above the ground The exact location of a nest can be determined by the position of the "windows."

Much unavoidable loss is occasioned by ant injury to cedar It has been estimated that in trees grown on swampy ground there is an average unavoidable loss of about 3 feet from the butt of every ant-infested white cedar, whereas on the higher ground the average loss is almost 6 feet. A part of this loss is, of course, due to butt rot, it is safe to say, however, that an average loss of at least 2 feet from the butt of every ant-infested tree is ascribable to ant injury.

Control of these insects can be secured in several ways. The simplest method is to inject carbon bisulphide, chlorpicrin, or some other fumigant into the nests Chlorpicrin, however, should not be used on living trees. Buildings should be set upon stone or concrete foundations so that the timbers will be kept dry Under such conditions, they will not usually provide favorable nesting places for these insects. In the forest, the ants gain entrance to the trees only through injuries Fire scars, ax marks, and other surface injuries should be eliminated as far as possible in order to prevent both wood rots and the entrance of ants.

Questions on Literature

1 Are there any ants other than *Camponotus pennsylvanicus* that are wood borers?

2. In what locations is injury to buildings by the carpenter ant most common?

3 Is the carpenter ant in any way beneficial?

4. What is the relationship between the carpenter ant and wood-rotting organisms?

5 How long may a colony maintain itself?

The Parandra Borer.—Another insect that is a frequent pest of wood that is not too dry is the parandra borer, *Parandra brunneæ* This pest belongs to the family Spondilidæ which is closely related to the Cerambycidæ It is widely distributed, probably occurring in all the parts of the United States and Canada that are wooded with hardwood trees The larvæ are elongate, cylindrical grubs very much like the round-headed borers in appearance The adults are glossy, chestnut-brown beetles about ¾ inch in length.

This borer attacks posts, poles, and the dead heartwood of standing trees of many different species of hardwoods They are found so frequently in chestnut trees that they have been called the chestnut pole borers Even though this insect attacks living

trees, it cannot be regarded as a primary species because it can only gain entrance to such trees through wounds, and then usually only works in the dead heartwood. Thus a tree is in very little danger of injury by this insect as long as it is in a healthy, vigorous condition. The parandra borer is usually associated with organisms of decay. It usually confines its activities to the lower parts of tree trunks or to the portion of a post or pole near the ground line

The adults emerge in late July and during August and soon thereafter begin their oviposition The females place their eggs in niches cut into the surface of dead wood or in the walls of old galleries. One egg is laid in each niche. In from 2 to 3 weeks the young larvæ hatch, whereupon they take up their labors as wood borers They tunnel through the heartwood and to a lesser degree in the sapwood making irregular tortuous galleries that may be several feet in length As they progress through the wood, they pack the frass and sawdust behind them in the gallery Many larvæ usually work together in a limited area, with the result that the entire heart of the tree or pole, at the point attacked, may be hollowed out. It is not usually very long after a tree or pole is attacked until organisms of decay join the parandra borer in its nefarious work, after which they work together until the tree or pole becomes so weakened that it breaks off at the point of attack It is probable that the larvæ require at least 3 years for their full development. When the larvæ are full grown, they hollow out pupal cells in the wood where they transform to pupæ and later to adults The adults cut their way to the outside.

The attack of this insect upon poles and posts can be prevented, at least in part, by treating the butt ends with creosote The treatment, if it is to be effective, should extend a foot or more above the ground When a pole is once attacked, it is practically impossible to free it of these insects. In standing trees, likewise, the best control is prevention Avoid wounds of any kind, for it is only in such places that the pest can gain a foothold Valuable shade or orchard trees that are infested may be treated successfully by surgical methods If the infested parts are carefully cut out, and the resulting cavity properly filled with concrete or asphalt, the injury can be checked. Surgical work of this kind is expensive and, unless carefully done, may prove worse than useless

Questions on Literature

1. How may the members of the family Spondilidæ be distinguished from their close relatives the Cerambycidæ?
2 How long will a pole well treated with creosote be immune to the attack of the parandra borer?
3 Is there any evidence to indicate that any food relationship exists between the parandra borer and the wood-rotting fungi with which it is associated?
4 In what parts of North America is the parandra borer most serious as a pest?
5 How should branches be pruned and wounds on shade and orchard trees be treated to prevent parandra infestation?

MARINE WOOD BORERS

The wood-boring insects are so numerous, and their work is so conspicuous and so familiar to everyone, that we are sometimes prone to think only of insects when we consider wood-boring organisms. As a matter of fact, however, wood provides food or shelter for many other forms of life Among the most important of these, from the economic standpoint, are the marine borers. In the strictest interpretation of the scope of Forest Entomology these organisms would be excluded, but in as much as they are often thought to be insects by the layman, and in as much as they are responsible for tremendous losses wherever wood is used in salt water, it seems appropriate that, at least, a brief discussion of them should be included here. The most destructive of the marine wood borers are the bi-valve mollusks called "shipworms" Much damage also results from the activities of several genera of marine crustaceans called "wood lice" The most common genus of these crustaceans is Limnoria. Each of these will be considered in turn

The Shipworms.—The shipworms, Bankia and Teredo, have been known to maritime peoples since the dawn of history and have been studied periodically from earliest times When we consider the time that has been spent upon the study of these creatures by investigators in centuries past, it is surprising that we know so little about them The imperfect state of our knowledge concerning this group is emphasized by the statement of Bartsch, published in 1922, to the effect that " . . the complete life history of not a single species is known today " It is not surprising, therefore, that methods used in the control of these pests are not entirely successful In recent years, the shipworms

have become increasingly injurious on the Pacific coast and now a concerted effort is being made to solve this serious problem

In the past, it was thought that there were only a few species of shipworms and that these were practically universal in their distribution. It has now been shown that many species exist and that, for the most part, each one is definitely limited geographically, just as terrestrial organisms are limited to definite ranges by ecological factors. Bartsch, in his "Monograph of American Shipworms," lists 30 distinct species that inhabit the waters of the Western Hemisphere.

Shipworms attack all kinds of wood. Very hard woods are somewhat resistant but are by no means immune to attack. It is said that very soft, porous woods, like palmetto, are not very attractive to shipworms but nevertheless they are attacked. In fact, shipworms will attack any wood that is submerged in salt water. The greatest damage is done to piling The replacement cost of piling destroyed annually by these animals is tremendous The following table will give some idea of the rapid destruction of piling that may occur in warm salt water.

LIFE OF PINE PILING IN DIFFERENT LOCALITIES*

Locality	Length of life in months	
	Average	Minimum
Colon, Panama	10	
Norfolk, Va	60	12
Newport News, Va	24	
Hampton Roads, Va	18	
St. Andrews, Fla	30	
Pensacola, Fla	30	12
Fort Morgan, Ala		12
West Pascagoula, Miss	30	12
Texas City, Tex	12	1
Galveston, Tex	18	5
Aransas Pass, Tex	12	3
Puget Sound, Wash	12	
Klawak, Alaska	36	18

* Smith, U S Dept Agr, Forest Service, Cir 128

As will be seen upon examining the above table, the injury by shipworms is greater in warm water than it is in cold On the Atlantic coast the pest is not serious north of the Chesapeake Bay,

although some species are able to live as far north as the Maine coast. On the Pacific coast the warm waters of the Japan current make conditions favorable for them as far north as Alaska Temperature, however, is not the only limiting factor in the life of these animals. Salinity of the water in which they are living has a decided influence upon them Fresh water is decidedly detrimental, this probably explains the comparatively long life of piling at Norfolk, Va

The shipworms in early life are free-swimming organisms and are provided with a bi-valve shell After certain stages have been passed in the water, the young mollusks attach themselves to

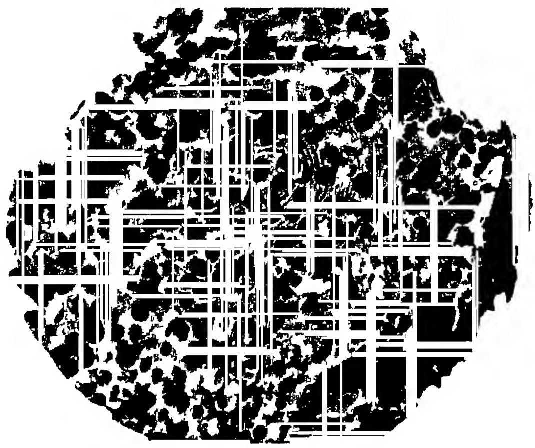


FIG 110 —The work of shipworms in a douglas-fir pile The wood has been almost completely destroyed by the burrows of these animals (*University of Minnesota*)

submerged wood. They bore into the wood leaving very small openings to the outside. Under favorable developmental conditions a pile may be attacked by thousands of these tiny creatures. Once inside the wood they grow rapidly and enlarge the tunnel to suit their increased size. The shell is used as a boring tool and is no longer needed for protection of the body The animal, in its burrow, is elongate and soft bodied, with the small chisel-like shell at the anterior end of the body and, at the posterior end, two tubes which are the exhalent and inhalent siphons Some of the larger species of shipworms may attain a length of 4 feet, under favorable conditions, while other species may never exceed 5 inches in length As the shipworm develops

within its tunnel, it secretes a calcareous, shell-like material which is used to line the burrow (Fig. 110). This shell-like lining is thicker in soft porous woods and thinner in harder woods

Considerable diversity of opinion has been expressed concerning the food of the shipworms. Some authorities maintain that the wood passes unchanged through their digestive tract, and that their entire food consists of plancton drawn in through the inhalent siphon. Recent work by several investigators has demonstrated, however, that this is not true. Although plancton probably forms a considerable part of the shipworm's diet, recent workers have shown that 80 per cent of the cellulose, and from 15 to 56 per cent of the hemicelluloses, contained in a douglas-fir pile were lost during the passage of the wood through the digestive tract of *Teredo navalis*. Furthermore, the proportion of reducing sugars was much higher in the caecum of *Bankia setacea* than in the original wood (Dove and Miller, 1923; and Miller and Boynton, 1926). From these observations, we must conclude that at least a part of the wood that passes through the digestive tract of these animals is digested and assimilated

Due to the fact that the entrance hole into the wood is very small and inconspicuous, there is usually little indication externally of the presence of the borers More than one-half of the volume of a pile might easily be destroyed without any evidence of injury being apparent on the surface Only by cutting into the pile can its condition be ascertained The portion of a pile that is most susceptible to shipworm injury is that between mean tidewater mark and about 4 feet below low water. The entrance holes are usually in this portion of the pile, although the active boring may be several feet above or below the point of entry

Control of shipworms is, theoretically, a simple matter, but, practically, it is anything but simple Protecting the susceptible parts of piling with any sort of covering will prevent the attack of these pests Metal sheathing of copper, iron, or any other metal is effective, but expensive, and not very durable owing to the corroding action of salt water. Cement casings of various kinds have been suggested and experimented with, but have not proved satisfactory because of cracks that are almost certain to develop as the result of expansion and contraction, or of wave action, or the battering of driftwood Likewise, coatings of tar, asphalt, pitch, and other similar materials give protection while they remain intact, but a single blow from a piece of floating

debris may easily open the way for infestation. Unbarked piling is not susceptible to shipworm attack while the bark remains intact, but it is next to impossible to find a stick with no break in the bark The success of all these mechanical-barrier methods of protection depends upon the maintainence of an unbroken covering The smallest break in the protective covering opens the wood to an attack which may easily result in the complete destruction of the pile. The only really successful method of protecting piling against shipworms, that has been developed so far, is impregnation with creosote. Surface treatment is not sufficient Only by pressure treatments, or by alternate hot-and-cold-bath treatment, can the wood be sufficiently impregnated to resist attack. Satisfactory impregnation is impossible to obtain with dense hard woods, therefore only pine, douglas fir, or other porous soft woods should be used.

Movable structures and boats may be protected by an unbroken covering of paint When borers have gained entrance into wooden vessels they can be killed by running the boats into fresh water

Questions on Literature

1 Are wooden boats an important factor in carrying shipworms from place to place?

2 Why are not all species of shipworms generally distributed throughout the oceans of the world?

3 What other animals are closely related to the shipworms?

4 How and where are the eggs of the shipworms fertilized?

5 What environmental changes may result in fluctuations of shipworm abundance in certain harbors?

The Wood Louse.—The wood louse, *Limnoria*, is another of the marine borers that does considerable damage along the Atlantic coast (Fig 111) It is confined to clear salt water and cannot endure fresh or turbid water Its temperature range is much greater than that of the shipworms and, as a result of this, it is found much farther north. It is very common along the New England coast and in the Bay of Fundy

The wood louse is a crustacean only about ⅛ inch in length and suggests in form a very small sow bug. Limnoria is gregarious and attacks piling and other structures in large numbers, usually near low-water mark As a general rule, the greater the difference between high and low tide, the greater will be the vertical distribution of these organisms

Limnoria finds both food and shelter in the wood that it attacks Each individual gallery is short, about ½ inch in length, and penetrates directly into the wood When large numbers attack a pile, their tunnels almost touch so that the thin walls between them are quickly worn away by wave action, leaving a new surface of wood ready for reinfestation. The progress of this injury is slower but more easily seen than the work of the shipworms

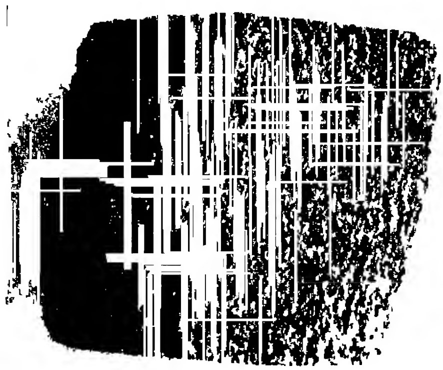


FIG 111 —Work of the woodlouse, *Limnoria sp* Each hole is the burrow of an individual crustacean

Heavily infested piling may lose an inch a year in diameter as a result of Limnoria attack. The control of Limnoria may be accomplished by impregnating with creosote wood exposed to salt water.

Questions on Literature

1 Describe the life cycle of the wood louse
2 Is the wood louse found in other parts of the world than along the Atlantic coast?
3 How do the adult wood lice differ from the immature forms?
4 In what way are the wood lice carried from one locality to another?
5. Do wood lice have any important natural enemies?

DRY-WOOD INSECTS

In the preceding sections of this chapter, only those insects and other animals that attack and injure moist wood have been studied Now we come to a group of insects that attack sound, dry wood. There are, comparatively, few groups of insects that are able to live throughout their entire developmental

period in this medium. It has been a constant quandary to entomologists how any insect could digest dry, sterile wood That some species are able to do so could not be denied, in view of the incontestible proof that a number of insects spend their entire developmental period in a medium which contains practically no micro-organisms or living cells of any sort. Recent investigations have made clear how this is accomplished, by demonstrating that at least some of the dry-wood insects have within their digestive tracts certain micro-organisms which are able to digest dry wood, and convert it into a form that can be used by the insect Without these organisms that comprise the intestinal flora, the insect would be unable to utilize the wood eaten. Thus, with the dry-wood insects, there is a symbiotic relationship with the organisms of the digestive tract which is fundamentally similar to the symbiotic relationship that exists between the moist-wood insects and the other organisms living in the wood.

Whether or not this relationship exists in the case of all dry-wood insects we cannot say, until the matter has received much more investigation, but, at present, it seems likely that it may prove to be the usual thing. In the case of termites, it has been demonstrated conclusively.

The Termites.—The white ants or termites are very destructive wood-boring insects. The name ant, as applied to this group, is a misnomer because these insects are not really ants but are members of the order Isoptera (Fig 112) The termites are, perhaps, the most destructive of all wood-boring insects in tropical regions In temperate lands, however, they are much less numerous and destructive than in the tropics, but they may occasionally be serious pests as far north as the Canadian boundary The latitude of Washington, D. C, marks the northern limit of the range in which they are commonly important pests

The termites are social insects living together in large colonies. They build their nests in living or dead trees, stumps, and in the timbers of wooden structures Some species may construct their nests in the ground and extend their tunnels into near-by wood Because they require moisture for satisfactory development, their nests are usually near or beneath the ground level. From these subterranean nests they extend their passages into any trees or adjacent wooden structures above ground Wooden

buildings that are in direct contact with the soil are particularly susceptible to infestation, but where termites are abundant they will sometimes gain entrance to structures that rest on stone or concrete foundations. The termites are all negatively phototropic, shunning light They also avoid exposure to the drying influence of the open air Whenever possible, they pass from

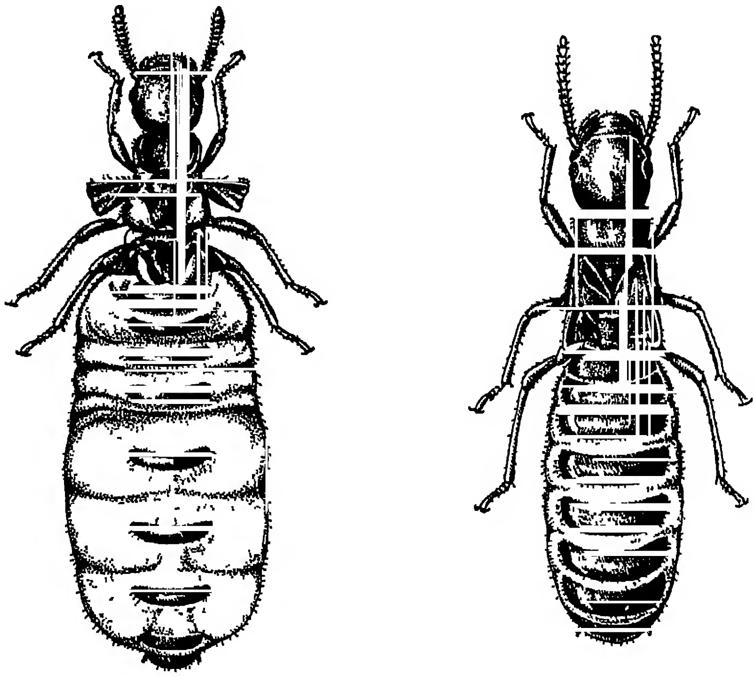


FIG 112—Adult termites greatly enlarged 1 Gravid female with segments distended 2 Worker (*Bureau of Entomology, U S Dept Agr*)

place to place through galleries that they cut in wood When their way is blocked by some hard substance, like stone or concrete, through which they cannot tunnel, they sometimes build covered passages of earth and wood pulp over the outside of such obstructions, in order that they may pass without being exposed to either light or dry air It is only by using these covered passages that the termites can gain access to buildings resting upon stone foundations

There are many species of termites, and each one has its individual differences in characteristics and habits. In general, however, they are quite similar. For the sake of brevity, only those general features of the life cycle and habits that are characteristic of all species, will be discussed here. More detailed information concerning individual species may be had by referring to literature cited in the bibliography.

The inhabitants of a termite nest are polymorphic and are good illustrations of specialization in connection with division of labor. Every nest contains the true males and females as well as the

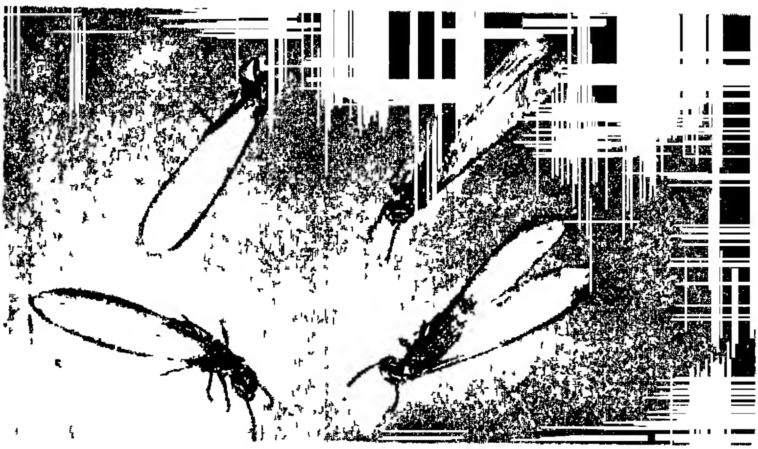


FIG 113—Winged termite adults, *Reticulotermes virginicus*. (*Bureau of Entomology, U. S. Dept. Agr*)

sexually imperfect workers and soldiers The sexual forms provide for the multiplication of the species; the workers care for the young, enlarge the nest, and perform other daily duties in connection with the provision of food and shelter for the colony; the group called "the soldiers" have for their duty the protection of the colony from attack by its enemies.

The termites are somewhat ant-like in appearance. They are white or light yellow in color, as might be expected of insects that live continually in the dark. Only the true males and females are winged (Fig 113) The young males and females are larger than the other members of the colony, except the laying queen which is exceedingly large In some species, where the workers are not more than ¼ inch in length, the queen may

be 2 or more inches long. The workers are small and wingless but otherwise they are similar to the sexual forms. The soldiers on the other hand, show marked morphological differences from the other casts, particularly in the development of head and mandibles. Although they are but little larger than the workers they are armed with large, strong mandibles thus making them formidable warriors.

In most groups the sexually perfect individuals, called "kings" and "queens," are winged. At certain periods these males and

FIG. 114.—Galleries of termites in wood. (*Bureau of Entomology, U. S. Dept. Agr.*)

females, after leaving the nest, mate and then establish new colonies. The queen then loses her wings and becomes little more than a machine to produce eggs. Her abdomen becomes distended with the eggs contained therein until she reaches such proportions that she cannot move. For the remainder of her life she is dependent for all her needs upon her attendant workers. The workers also care for the eggs and the young, as the colony increases, they also enlarge the nest and extend the tunnels.

In the tropics, the problem of protecting buildings from termite attack is exceedingly important. In fact, unless adequate

provision for this protection is made, a wooden structure has an extremely short life. In unprotected buildings, these insects may work throughout the timbers until, finally, the structure will collapse (Fig 114). Even furniture or books in an infested building are often attacked. A table, if left standing in one place for some time, may be infested and destroyed by way of tunnels extending from the floor below. Books and other printed matter, especially when such materials are stored in basements, are likely to be destroyed by these insects.

In termite control, as in the control of most insects, prevention is much more effective than cure No part of a wooden building in termite-infested localities should rest directly on the ground Every part should rest upon a stone or concrete foundation The termites can only gain entrance to such buildings by bridging over the foundation with the covered passages referred to above. If these passages are destroyed as soon as they appear, the building will be safe from attack Wood treated with creosote is comparatively immune to termite attack; consequently, wood in contact with the ground should always be so treated, in regions where termites are abundant. Some species of tropical woods, greenheart and mahogany for example, are relatively immune. The use of these immune species is obviously desirable whenever they are obtainable, but, unfortunately, the supply is too limited for general use. One native wood, redwood, is decidedly resistant to termites

Under certain conditions, it may be necessary to destroy termite nests. This may be accomplished by fumigation. one of the materials most generally recommended for this work is carbon bisulphide. This volatile liquid may be injected into the nest after which the opening to the outside should be sealed This chemical is inflammable and highly explosive; for this reason it should be used with extreme care. Recent work has shown that other materials may be used just as effectively as, and in some instances more effectively than, carbon bisulphide Cyanogen gas produced by the decomposition of calcium, sodium, or potassium cyanide has been used effectively. One satisfactory method of applying this material is to blow a dust of calcium cyanide into the nest Calcium cyanide decomposing, as it does, on exposure to the air, liberates cyanogen gas with destructive results to the termites Liquid cyanide has also been used effectively Chlorpicrin, one of the materials used for a trench gas in the World War, has been used recently as a

fumigant for certain insects and should prove effective in destr ing white-ant nests. It has several distinct advantages o both cyanide and carbon bisulphide; and although it is a v poisonous gas, it is so irritating to the mucous membranes the nose and eyes that no person is likely to stay in a place wh even a small quantity of chlorpicrin is in the air Thus, it safer to use than either of the other above-mentioned mater because it waves its own red flag of warning

Questions on Literature

1 What species of termites are injurious on the Atlantic coast?

2 Do these insects have complete or incomplete metamorphosis?

3 Why are these insects more injurious in the tropics than in temper regions?

4 Is there any danger that new injurious termites may be accident introduced into the United States from foreign lands?

5. What materials, other than creosote, have been recommended protect wood against termites?

The Powder-post Beetles.—The name "powder-post beetl is applied to representatives of several small families of t Coleoptera that feed upon dry wood The two families th contain most of the powder-post species are the Bostrych and the Lyctidæ. In America, the species of the genus Lyct are the most common insects of this group. *Lyctus planicol Lyctus parallelopipedus*, and *Lyctus cavicollis* are three comm species of these beetles.

The beetles of this group are called "powder-post beetle because of their effect upon the wood in which they work Th may reduce the entire interior of a piece of wood to a fine, flo like powder, leaving only the exterior shell intact These beet are pests of the sapwood of broad-leaved trees Wood of oa hickories, ash, and poplars are frequently injured Since t heartwood is immune, the injury is always confined to the sa wood

The powder-post beetles feed only in dry, well-seasoned woo As a rule, a full year of air drying is required before the wo becomes suitable to the taste of these beetles, although sm pieces may dry out more rapidly and become susceptible attack in eight months after cutting Kiln-dried material susceptible to attack as soon as it leaves the kiln

One full year is required to complete the life cycle of the insects The adult beetles emerge in the early spring, and it is

that time that the injurious work of these pests is most likely to be noticed It is not at all uncommon during the spring months for dealers in such hardwood products as handles and wagon or automobile stock to discover that they have been harboring, unaware of their presence, these unwelcome guests (Fig 115) Sometimes, when infestation is severe, a merchant's entire supply of axe and shovel handles may be destroyed before he realizes that the insects are present. Occasionally, infested

Fig 115 —A hickory shovel handle destroyed by powder-post beetles

flooring may be laid and finished without anyone's realizing that the wood is not perfectly sound, and it is not until the beetles emerge in the spring that their presence is recognized Even furniture may be infested. When this occurs it usually happens before the wood has been finished Until they emerge as adults there is often no sign of the infestation Then the wood may be peppered with the small, round, exit holes which the beetles have cut to the outside Fine, powdery borings, previous to or at the time of emergence, is another indication of infestation

During the brief period of flight in the spring, mating takes place and the females seek out suitable places for oviposition The eggs of the lyctus powder-post beetles are laid in pores of the sapwood (Fig. 116). When the young larvæ hatch from these eggs they find themselves in a desirable location and immediately proceed to make the best of their opportunities Their first meal consists of the remains of the eggs from which they hatched, but from then on they must find sustenance in the solid, dry wood The larvæ cut irregular winding galleries in the wood As they progress, they pack the finely pulverized frass behind them in the tunnel The winter is passed in the larval stage

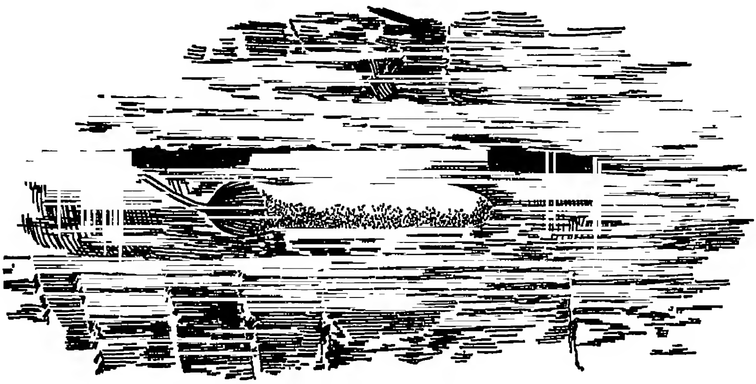


FIG 116—An egg of a lyctus beetle inserted in a sapwood pore (*Bureau of Entomology, U S Dept Agr*)

In early spring the transformation, first to pupæ and next to adults, takes place within the wood The adult beetles then cut their way to the outside in order to emerge

Prevention is the keynote of powder-post-beetle control because after wood is once infested by these insects it is usually fit for nothing more than firewood. In lumber yards and manufacturing plants, where large quantities of hardwood stock must be kept on hand, thorough inspection of wood more than one year old should be made annually for the purpose of eliminating any stock that may have become infected The best time for inspection is in the winter months Infestation is usually indicated by small quantities of fine borings that sift out of infested pieces Infested pieces break easily, exposing the powder-filled tunnels to view

In order to simplify inspection, heartwood and sapwood stock should not be piled in one pile The heartwood is not susceptible and need not be inspected, hence separate piles of sapwood and heartwood would reduce the labor of inspection. Wood in storage should also be classified according to age because the oldest wood is most likely to be infested. All new stock should be carefully inspected to prevent introducing the beetle into uninfested sheds and storehouses Any suspicious material should be kept under observation for several months.

Fig 117 —A piece of wood in which the unpainted portion was attacked by powder-post beetles while the painted and varnished portions, behind the knife, remained unattacked (*Bureau of Entomology, U S Dept Agr*)

Rapid utilization will greatly reduce the chance of infestation in storage sheds in as much as wood that is less than a year old is never a menace. Wood kept on hand for several years is likely to become a great danger if it becomes infested Wood-working industries should always utilize first the oldest stock on hand. All waste sapwood should be burned or hauled away from woodworking establishments· under no circumstances should it be allowed to accumulate or else powder-post beetles may become established in these waste piles and from there infest the stock piles

Ordinarily the safest course of procedure in dealing with infeste material is to burn it. Sometimes, however, a part of the stoc that has not been too heavily injured may be saved if the insec working in it can be killed To accomplish this, the dipping infested wood in kerosene or in orthodichlor benzene has bee recommended Repeated applications of either of these materia to infested wood, by means of a brush or a spray, will kill th insects Both of these materials will evaporate leaving the woo unstained Dipping in a mixture of hot kerosene and creoso has also been recommended. This, however, discolors the woo In using hot inflammable oils such as kerosene, it should be born in mind that to heat liquids of this sort over an open flame is invite disaster, since a fire or an explosion is almost certain to b the result Inflammable oils should always be heated by stea coils arranged in the bottom of the dipping vat.

One of the most effective means of protecting susceptib wood from the attacks of powder-post beetles is by treatme with boiled linseed oil, varnish, or paint (Fig. 117) It will b remembered that the lyctus powder-post beetles deposit the eggs only in open pores of wood Treatment with any of th materials above mentioned will close the pores and prevent ov position by the beetles In many lumber yards it is customa to paint the ends of hardwood lumber to prevent checking Th treatment also protects the wood against end attack by powde post beetles. It does not, however, prevent side attack.

Questions on Literature

1. What powder-post beetles are common pests in European countries?
2. Have any European species been introduced into America?
3 Are there any powder-post beetles that attack conifers?
4 What close relatives of the powder-post beetles attack moist wood?
5 What other families of beetles in addition to the Bostrychidæ a Lyctidæ attack dry wood?

CHAPTER XV

SAP-SUCKING INSECTS

All of the insects discussed in the preceding sections feed upon the tissues of trees by ingesting the solid parts. All of them have mandibulate mouth parts In addition to these chewing insects, there is a large and important group the species of which live upon sap. Their mouth parts are of the sucking type in which the mandibles and maxillæ have become slender, bristle-like organs enclosed in a sheath, the labium This forms a beak which is used for the purpose of piercing tissues and sucking the juices therefrom. The sucking insects that attack trees belong to two orders, the Hemiptera and the Homoptera Both of these orders contain families that are exclusively phytophagous

The effect of sucking insects upon trees is much less conspicuous than is the effect of defoliators, meristem insects, or wood borers The insects of this group seldom kill trees directly, but they may, nevertheless, have a distinctly injurious effect upon the forest Because their work is not conspicuous, most of the sucking insects of forest trees have received comparatively little consideration On orchard and shade trees, on the other hand, they are acknowledged to be exceedingly important enemies As the intensity of forest management increases, the importance of these species in the forest will doubtless receive increasing recognition, for, unquestionably, the sucking insects do as much actual damage to forest trees as they do to orchard and shade trees

Sucking insects may injure plants in two ways: First, directly by sucking the sap and thus robbing the plant of a part of its supply of food and water, and second, indirectly by disseminating plant diseases It has been shown in the case of woody shrubs, such as raspberry, and also in the case of many herbaceous plants that some of the so-called physiological diseases are really caused by disease organisms that are carried by sucking insects In some instances, the insect may serve in the capacity of an intermediate host for the disease The mosaic diseases are transmitted from plant to plant by sucking insects and, in some cases, this is the only

way that these diseases can be carried from one host to another. How important the insect-borne diseases may ultimately prove to be in forests, time alone can tell. Up to the present, they have received practically no attention from either plant pathologists or entomologists.

FIG 118 —Scars on an aspen twig caused by the oviposition injury of tree hoppers

Many sucking insects may also injure trees mechanically, by ovipositing in them In fact some species, for example certain tree hoppers (Membracidæ), do not generally feed upon trees at all, but they still may seriously injure or even kill trees by filling the branches with their egg slits (Fig 118).

The species of sucking insects that attack trees are so numerous that space will not permit a full consideration of this important group The discussion will be confined to a few representative types of the more important families

HEMIPTEROUS INSECTS

The order Hemiptera embraces a large number of sucking insects. The members of this order are the true bugs, and it is only to this group that the name bug can be correctly applied A number of Hemipterous families are predaceous, some of them upon forest insects, but it will be necessary to pass them by and confine the discussion to those that suck the sap of trees

The Plant Bugs.—The members of one family of the Hemiptera, the Miridæ, are known as plant bugs and contain many tree species Every tree of every species is infested with its share of these insects, but they seldom occur in sufficient numbers to be recognized as injurious pests of forest trees. A few of them, like the tarnished plant-bug, *Lygus pratensis*, and the box-elder plant-bug *Leptocoris trivittatus* (Fig. 119), are sometimes injurious in nurseries. The eggs of these insects are deposited in slits which the females cut in the twigs and small branches of trees The young that hatch from these eggs bear a decided resemblance to the adult, except that they have no wings They run about actively and get their food by puncturing the leaves or stems,

and sucking the sap. The metamorphosis of these, like all other Hemiptera, is gradual. With each succeeding moult, the nymphs become more and more like the adult until the final moult, when they appear as winged imagos No satisfactory control for these insects has ever been developed Even when occurring on nursery stock and fruit or shade trees they defy control They are resistant to contact sprays and their method of feeding precludes the possibility of killing them with a stomach poison.

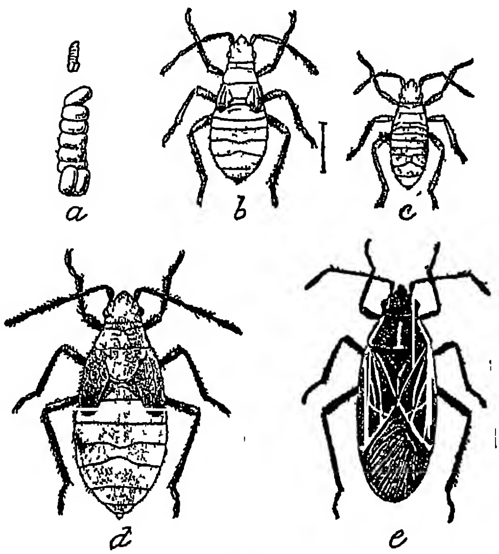


FIG 119—Various stages of the box-elder plant bug, *Leptocoris trivittatus* a Eggs b, c, d Nymphs e Adult (*Bureau of Entomology, U S Dept Agr*)

The Lace Bugs.—Another important family of the Hemiptera is the family Tingidæ, the lace bugs. These insects are very small in size, usually not much over ⅛ inch in length, but they are nevertheless very striking in appearance The hemelytra are thin, almost gauze-like in structure, and are marked by a network of fine lines that give the insect a lace-like appearance Lateral expansions of the prothorax that are similar in structure and appearance add still more to the lace-like effect (Fig 120)

Unlike the leaf hoppers, which are very active in all stages, the lace bugs lead a very sedentary life Their entire developmental period may be spent upon a single leaf Injury done by them is much more likely to be observed than that caused by the plant

bugs, in part because it is usually more localized, and in part because the insects themselves are more easily seen.

The lace bugs sometimes occur in extremely large numbers and in some years may destroy over extensive areas practically all the foliage of their host trees They are not, however, tree killers They attack trees of all sizes, but appear to prefer trees of sapling or small-pole size. Drake (1922) considers one of the tingids, *Corythuca pallipes*, to be "the most injurious leaf-feeding insect on yellow birch" in certain parts of New York State These insects are sometimes very seriously injurious to hardwood trees growing in nurseries The birch is one of the common hosts for a number of lace bugs, but other hardwood species (for example ironwood, sycamore, oak, maple, willow, and basswood) are often heavily attacked

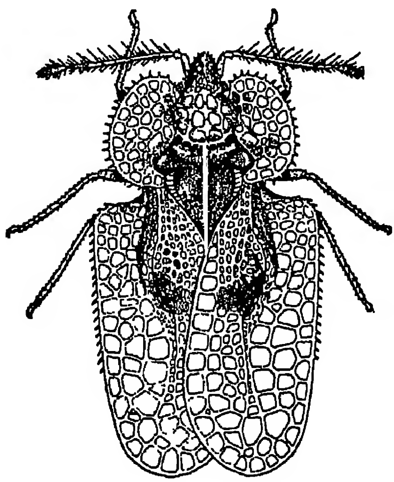


FIG 120 —The sycamore lace-bug, *Corythuca ciliata* Adult, greatly enlarged (*Bureau of Entomology, U S Dept Agr.*)

The life history of the lace bugs is in some ways quite similar to that of other Hemiptera. The eggs are deposited on the under side of leaves of the host tree, usually in the veins Each egg is inserted partly in the leaf tissues, sometimes singly but usually in groups No definite method is followed in arranging the groups. The eggs are dark in color, rather elongate, and slightly curved in form, with the upper end somewhat constricted and closed with a lighter-colored cap or lid They hatch in about 10 days after deposition

The young nymphs that hatch from these eggs insert their proboscides into the leaf tissues and suck out the sap During the early nymphal stages they are usually gregarious When they become mature they generally scatter The adults feed on both the upper and lower surfaces of the leaves, whereas the nymphs practically always feed only on the lower side

Almost all the lace bugs have two generations a year in the latitude of New Jersey. It is probable that farther north they

may have only a single generation, while in the South they may have more Most of the species pass the winter in the egg stage, although a few become adults before hibernation These overwintering adults hide themselves away beneath bark, or in the litter beneath the trees, or in any other sheltered location.

The control of lace bugs in nurseries and on shade trees can be accomplished with comparative ease Spraying with a contact insecticide is usually effective On lawn trees the insects may be held in check by washing the foliage thoroughly with a forcible stream of water from the garden hose Whale-oil soap at the rate of 1 pound to 6 gallons of water has been recommended In spraying for these and other sucking insects, it is important that the spray be applied with considerable force This means that with a 50-foot lead of hose a pressure of 200 to 250 pounds should be maintained at the pump.

Questions on Literature

1 What are some of the most important species of lace bugs?

2 Are any of these species general feeders or is each one limited to a single host or to a small group of host species?

3 How do the nymphs differ from the adults in appearance?

4 At what stage in the nymphal development do the wing pads first appear?

5. What are some of the enemies of the lace bugs?

CERTAIN HOMOPTEROUS INSECTS

Many members of the order Homoptera are important enemies of forest and shade trees· in fact almost every family of the order has representatives that feed upon trees The most important groups, from the viewpoint of forest entomology, are the aphids or plant lice, the adelgids, and the scale insects, but members of other families are sometimes important locally. For instance the cicadas, although they do little damage to the tree during their long, subterranean, developmental period during which they feed upon tree roots, sometimes cause heavy injury to shade and nursery trees at the time of oviposition Certain species of leaf hoppers are primarily tree insects The tree hoppers feed on herbaceous vegetation but they sometimes severely injure or even kill trees in which they oviposit heavily. This injury is particularly common in nurseries and in the farm windbreaks and groves of prairie regions The frog hoppers or spittle bugs injure and sometimes kill pines when they attack these trees in large numbers The chermids or jumping plant lice are particularly

injurious to orchard trees, sometimes even killing them The members of these families, however, in spite of the fact that they sometimes are injurious, cannot be regarded as forest pests of primary importance. A detailed discussion of most of them will, therefore, be omitted here

The Periodical Cicada.—In addition to the aphids, the adelgids, and the scale insects mentioned above, we shall discuss a representative of only one other Homopterous family. That is the Cicadidæ. The more common species of this family are well known to almost everyone, for those who do not know the insects by sight are familiar with the strident, rattling song of the male

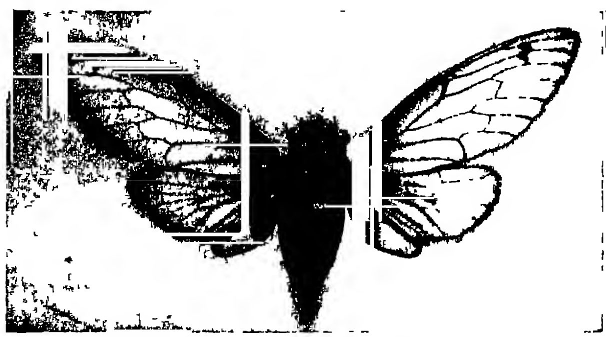


FIG 121—An adult of the periodical cicada, *Tibicina septendecim* (*Bureau of Entomology, U S Dept Agr*)

that is so characteristic of warm summer days. They are called "harvest flies" and sometimes incorrectly termed "locusts" One of the most injurious and best-known members of this family is the periodical cicada *Tibicina Septendecim,* this species will serve well as a representative of the group (Fig 121)

The periodical cicada appears from time to time in great swarms, particularly in regions of eastern North America that are heavily wooded with hardwood trees. The female lays her eggs in slits that she cuts in small twigs and branches of woody plants When the cicadas occur in great numbers, every available twig may be filled with egg slits with the result that many twigs will be killed This is not particularly injurious to mature forest trees, but to young trees in the forest or the nursery it may be disastrous (Fig 122).

The periodical cicada has an astonishing life history which is, indeed, stranger than fiction. The full-grown nymphs, some-

Fig 122 —Injury to the small branches of hardwood trees caused by the oviposition of the periodical cicada On the left recently injured twigs are shown On the right are old injuries, healing over (*Bureau of Entomology, U S Dep't Agr.*)

times called pupæ, emerge in spring and early summer from the ground where they have been entombed while passing through the developmental stage. In certain years, they appear in such quantities that large areas of ground, from which they have emerged, is literally peppered with their exit holes. In some places, fifty to one hundred exit holes per square foot of soil surface is not uncommon.

The full-grown nymphs are curious, heavy-bodied insects with a broad, blunt abdomen and powerful legs. As soon as they leave their burrows, they climb upon any convenient object and there hook their claws firmly into the supporting surface and come to rest. Before very long, a split appears along the back of the thorax, and the adult emerges leaving the empty nymphal skin hanging where it was fastened. Trees, shrubs, fences, poles, and any other convenient objects, in years when cicadas are abundant, may be covered with these cast skins

The adult, when fully pigmented, is dark brown to black in color, with red eyes When the insect is in a resting position, the clear, membranous wings are folded over the body like a tent. The head and thorax are broad and the abdomen is tapering. The females are each armed with a strong ovipositor that might appropriately be compared to a pair of chisels By means of this powerful tool they gouge out slits in twigs and small branches in which to deposit their eggs. The height of the oviposition period usually comes in June. The period of incubation is long, requiring 6 or 7 weeks When the young nymphs break from the eggs they drop to the ground and promptly burrow downward into the soil.

There, at a depth of about 2 feet, they hollow out an earthen cell next to one of the small roots of some tree or shrub The insect then inserts its beak into the tissues of this root and proceeds to suck the juices therefrom. This liquid food provides the only nourishment for the insect. The periodical cicada grows very slowly. Safe in the seclusion of its earthen cell, there is no need for haste in completing its development. The slight mechanical injury to the root resulting from the insertion of the cicada's beak is of little consequence; therefore the root provides for the nymph a regular and certain source of food which will continue for an indefinitely long period Thus, unlike most insects, the length of life of the nymph is not limited by changing food conditions The combination of a readily avail-

able, permanent food supply with a habit of life that gives the insect almost perfect protection from its enemies makes possible an exceedingly long developmental period. The periodical cicada lives for seventeen years in the nymphal stage. This is the longest life cycle known for any sucking insect.

Most other insects which have long life cycles have overlapping broods, some of which emerge each year. This is not so with the periodical cicada. One season all the individuals of a brood emerge simultaneously in a locality. The insect may then be so abundant as to be a veritable scourge. In the following years not a single specimen of the insect will be found and not until the seventeenth year will they again appear. In some localities, however, there may be more than one brood. The adults of the several broods need not emerge at the same time, but the generations of every brood are, without exception, always separated by seventeen years. The broods of this insect are well known to entomologists. Each one is numbered and the time and geographical distribution of each emergence can be prophesied exactly. In the South, there is a race of this species which has a somewhat shorter life cycle. Only 13 years is required for its development. It is thought by some that this is a different species, but the general consensus of opinion appears to be that it is merely a biologic variety.

The control of this insect by direct means is virtually impossible. If the branches of trees and shrubs that contain eggs were pruned off and burned before the eggs hatched, the numbers of cicadas could doubtless be reduced. But pruning of this sort is usually out of the question of the tremendous numbers and general distribution of the eggs.

Natural enemies are important aids in reducing the number of cicadas. Birds, particularly those of the blackbird group, are very fond of the newly emerged adults and consume them by the hundred. The house sparrow and many other birds are said to feed upon this insect. Just before emergence the nymphs come up to the surface of the soil. Here they are sometimes found and destroyed by scratching birds, moles, or hogs.

Questions on Literature

1. Are any species of cicada, other than the periodical cicada, important economically?
2. How many eggs will a single female cicada lay?

3. How is the song of the cicada produced and what is its apparent purpose?
4 Have cicadas ever been used for food by man or other animals? If so when and how?
5 How many broods of the periodical cicada are now recognized?

The Aphids.—Among the homopterous sucking insects the family Aphididæ stands out prominently as an exceedingly important group. The members of this family are called aphids or plant lice. They are abundant in numbers, both of individuals and of species, and they are so generally distributed that it is scarcely possible to find a tree of sapling size or larger which is not infested by them to a greater or less degree

FIG 123 —Aphids feeding on a stem The individuals that appear to be swollen are parasitized The emergence hole of a parasite may be seen in the abdomen of the uppermost aphid

The aphids are usually very small, soft-bodied insects Their bodies are generally pear shaped. The legs are long and slender. With most species, on the dorsal side of the abdomen near the caudal end, there is a pair of cornicles Aphids may be either winged or wingless. When wings are present, all four of them are transparent, delicate, and provided with a few simple or branched veins (Fig 123)

When aphids occur in comparatively small numbers, the direct injury that they cause is comparatively slight, but when they become very abundant, as they frequently do under favorable weather conditions, their injury to the trees is often great They are not tree killers, however, and, with the exception of young trees, the injury which they cause usually results only in a reduced rate of growth and in a generally unthrifty condition of the infested trees Trees injured by aphids may succumb to

secondary insects which they could resist when in vigorous health

Aphids have received much study as agricultural and horticultural pests, but because our forestry methods are decidedly extensive rather than intensive, these insects have received little attention as forest pests. Nevertheless, in view of their abundance, it cannot be doubted that the aphids comprise an important group of forest insects. In nurseries and in young plantations the aphid problem is often exceedingly important The

Fig 124 —Galls of the poplar gall-aphid, *Pemphagus populi-transversus* One of the galls has been opened to expose the interior (*University of Minnesota*)

number of aphid species that attack trees is so great that it seems desirable here to treat the entire family as a unit, rather than to discuss a limited number of individual species.

Different aphids have different habits. Some of them live on the bark of the trunk and large branches, others confine their feeding activities to the leaves and green tips, while still others feed upon the roots of trees. Some of them cause the formation of galls, particularly on the leaves They live within these galls and thus the tree provides them with both food and shelter (Fig 124) Other species provide shelter for themselves by causing the leaves on which they are feeding to curl about them.

Still others live unprotected on the surface of the trees. Some aphids are provided with glands which secrete a flocculent, wax-like material which collects over the insects, and affords them some protection from their enemies and from the weather.

All aphids secrete a sweet material called honeydew which is highly prized for food by ants and other insects For this reason,

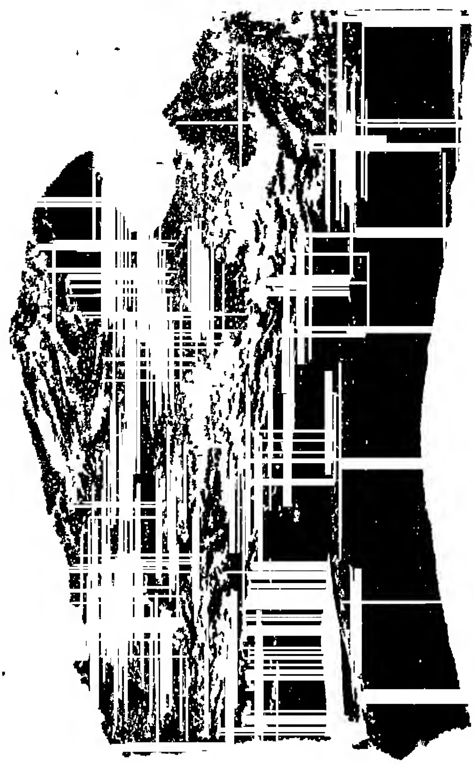


Fig 125 —Aphid eggs on the bark of an oak tree (*University of Minnesota*)

it is a common sight to see ants among groups of aphids busily collecting this sweet liquid. In some instances interesting symbiotic relationships have arisen between ants and aphids. The ants care for the aphids and in return receive honeydew. It is because of this relationship that aphids are sometimes called "ant cows."

Although the habits of the various species of aphids vary greatly, the general features of the life cycle are quite similar for

most of the common species. The true aphids pass the winter in the egg stage on the host tree (Fig 125) In the spring, with the appearance of green vegetation, parthenogenetic females hatch from these overwintering eggs These females are called "stem mothers." It is from them that the summer generations arise

The stem mother, or *fundatrix*, as she is sometimes called, is wingless in most species These young are all agamic females which in their turn reproduce parthenogenetically and are called wingless agamic forms or *spuriæ apteræ*. From these may be produced a number of generations of similar forms, each generation giving birth to living young Reproduction is very rapid In from 5 to 7 days after an individual is born, she will, in her turn, begin to produce living young It is not surprising, therefore, that the aphids build up rapidly in number as the season progresses

In certain generations another type usually appears. These are winged agamic females and are known as migrants, or *spuriæ alatæ* Frequently, both winged and wingless forms are present in the same generation These forms are often produced by the *spuriæ apteræ* at a time when the food plant has become crowded. In certain species, the migrants are produced directly from the stem mother These migrants leave the plant upon which they have been feeding to seek fresh food Some species seek out plants of the same species as that which they left, but a large number of aphids have an alternate host to which the migrants fly When this is the case, the host upon which the stem mother and the succeeding generations are produced is called the "primary host," the host species to which the migrants fly is termed the "secondary host"

On the new host the migrants give birth to winged or wingless agamic forms. A number of generations of these usually occur On a secondary host the wingless agamic forms may or may not resemble the form on the primary host Sometimes they are so different that they have been regarded by entomologists as distinct species until a careful study of their life history has disclosed their identity. The members of the last generation of this series give rise to the true sexes and are therefore known as *sexuparæ* In those species that have alternate hosts this generation is winged, at least in part, whereas species which always remain on the same host may be wingless

The winged *sexuparæ* that are to produce the sexually perfect females fly from the secondary host back to the primary host. There they give birth to the oviparous females which only appear at this stage in the cycle The males are usually produced by non-migrating *sexuparæ* on the secondary host and migrate to the primary host. Mating takes place there and eggs are deposited. In some species, each female produces only a single fertilized egg, whereas, in others, several eggs may be produced

The control of aphids is practically the same for all species. In the forest, no control is practiced, and little thought has been given to this particular side of the aphid problem. There is a possibility that some species that require alternate hosts may ultimately be controlled, in intensively managed forests, by eliminating one of the hosts But such a development is probably far in the future. For the present, it seems likely that the control of aphids will receive little consideration in established forests. Only in nurseries, in young plantations, and on ornamental trees will they receive much consideration

In such instances, direct control measures will usually be used. Spraying is the surest and best means of controlling these insects on standing trees During the growing season, nicotine sulphate in soap solution at the rate of 1 part of nicotine sulphate to 600 or 800 parts, by volume, of strong soapsuds will usually give satisfactory control when thoroughly applied as a spray. The overwintering eggs may be destroyed by a dormant spray of lime sulphur or miscible oil.

Stock that is infested in the nursery should not be set out, either in forest or ornamental plantations, without its first being treated to destroy the aphids Successful treatment may be accomplished in two ways The planting stock should either be dipped or fumigated. Dipping is apparently a little more certain than fumigation. Either lime sulphur or miscible oils, at winter strength, will usually give satisfactory results Another material that is apparently satisfactory for this purpose is nicotine oleate. This material is made by mixing a free nicotine solution with oleic acid, at the rate of 10 parts of a 40 per cent free nicotine solution with 7 parts of commercial oleic acid. It is an effective ovicide when used at the rate of 1 part of nicotine oleate to 40 parts of water.

Questions on Literature

1 Under what conditions may agamic females lay eggs?
2 What are some of the important gall aphids?
3 What economically important aphid feeds on elm that has apple for it alternate host?
4 What is honeydew and how is it excreted?
5 What important plant diseases are spread by aphids?

The Adelgids.—The adelgids (chermes) are close relatives of the true aphids but differ from them in several important respects For instance, the adelgids have no cornicles, and both the parthenogenetic and sexually perfect females lay eggs. The adelgids were formerly called "chermes" but recent taxonomic study has shown that this name, by right of priority, belongs to certain of the jumping plant lice of the family Chermidæ Thus the name "chermes" must be replaced by the name "adelges," in spite of the fact that these insects have become well known, not only to entomologists but also to foresters and others, by the former name But the temporary confusion, that is bound to result, will not be so serious as the permanent confusion, that would certainly occur, if the common name "chermes" were retained for the adelgids

The adelgids all feed upon coniferous trees and, in some instances, they are responsible for much injury In general, they may be regarded as more injurious than the true aphids They are particularly injurious to trees that are growing under unfavorable conditions. The life cycle of these insects is even more complicated than that of the true aphids. Most of the species have alternate hosts but in every case the primary host is a spruce On the spruce, the adelgids form leaf galls of different types varying from a condition in which the bases of the needles are slightly swelled to a condition in which the needles of the new growth form a closed, cone-like gall. Where these galls are formed, a part or the whole of the infested portion dies. It is obvious that when a large proportion of the tips are attacked, year after year, serious injury to the trees will result. In the eastern part of this country and Canada the adelgids are common but are not usually considered dangerous pests. In the Northwest, however, these insects have at times been responsible for serious injury

The alternate or secondary host of the adelgids varies with different species (Fig. 126) It may be any one of the following

genera: Abies, Pseudotsuga, Larix, Tsuga, or Pinus. On the secondary host no gall is formed The insects live either upon the bark or the needles The injury that they do to the secondary host may or may not be severe In the case of the pine bark-adelges, *Adelges pinicorticis*, the injury is sometimes very severe. It is especially injurious to young trees growing under semisup-

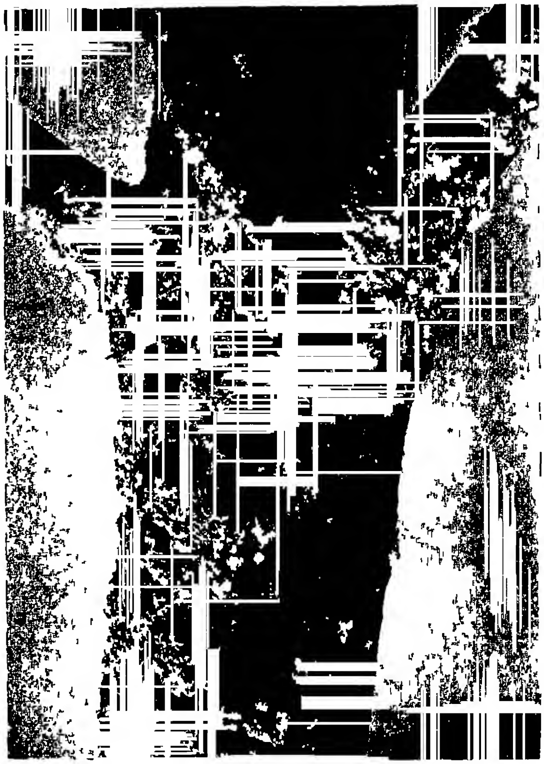


FIG 126 —Adelgids on a secondary host, white pine On this host the insect is called *Adelges pinicorticis* (*University of Minnesota*)

pressed conditions and to older trees on poor sites. The activities of this insect may frequently so weaken the trees that they succumb to the attack of bark beetles The full life cycle of the pine-bark adelgid is not known

The adelgids are small insects, oval in shape, with mouth parts of the sucking type They are provided with wax glands that excrete a flocculent, waxy mass that covers the insects and

their eggs Like the aphids, the adelgids have some winged generations and others that are wingless

Adelges cooleyi is one of the American species that has been carefully studied Its life cycle will serve well as an illustration of that of the group as a whole. This species may breed upon several primary hosts It has been reported as attacking colorado blue spruce, *Picea pungens;* engelmann spruce, *Picea Engelmanni;* and sitka spruce, *Picea sitchensis*. The secondary host is douglas fir, *Pseudotsuga taxifolia*

The species overwinters as an immature stem mother or *fundatrix vera* as she is sometimes called This stem mother is always found on spruce and always hatches from a fertilized egg. She is a wingless agamic female. When spring arrives, she soon completes her development, during this period she secretes a large quantity of white, waxy wool. When she becomes mature, she deposits a large number of unfertilized eggs beneath this wool-like covering These eggs laid by the stem mother give rise to a generation called "gall dwellers" or *gallicolæ.*

As soon as the young gall dwellers hatch, they make their way to the expanding new growth There they settle down to feed Each tiny individual takes up her position at the base of a young needle on an expanding tip, sometimes alone but often with some of her sisters She inserts her mouth parts into the succulent tissues and sucks the sap The stimulation resulting from the presence of adelgids, the exact nature of which is unknown, causes the basal portion of the leaf to thicken and expand, until it forms a shelter over the young insects Usually all the needles on a shoot are attacked at practically the same time and respond in similar manner These basal leaf swellings coalesce and form a cone-like gall on the new growth (Fig 127). The form of the gall varies with different species of adelges but is constant for the same species. The individuals that arise from a single stem mother may number from 300 to 500 When the gall dwellers are full grown, the galls open The young adelgids then crawl from the gall and settle on the spruce needles Here they cast their nymphal skins and emerge as winged insects. This takes place about the middle of June

These winged forms are called *gallicolæ migrantes* or migrating gall dwellers. They fly to douglas fir and, after settling upon the needles, each insect lays from 100 to 150 eggs. In some adelgids the winged generation of gall dwellers have two alter-

natives. They may either migrate to the secondary host or the may remain upon the primary host In the latter case they ar called *gallicolæ non migrantes*, or non-migrating gall dwellers, an give rise to forms similar to the true stem mothers which over winter and lay eggs, in the following spring, for another gen eration of *gallicollæ* on the primary host. In this way, a complet asexual cycle may occur on the spruce

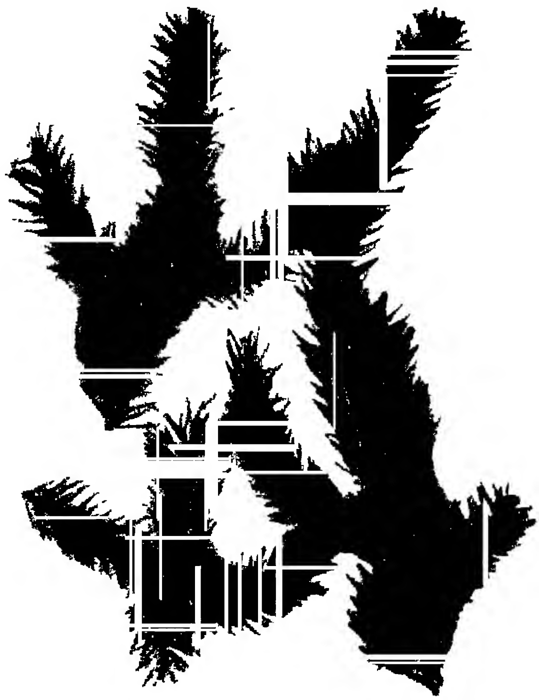


FIG 127 —*Adelges abietis* galls on norway spruce

The eggs on douglas fir laid by the *gallicolæ migrantes* hatch i about a week into forms that are called the colonist brood or *colonici*. These are wingless forms that differ in appearanc from the spruce-inhabiting forms from which they arose Th members of the *colonici* generation that arise from the *gallicol migrantes* are sometimes called "false stem mothers" or *fundc trices spuriæ*. They pass the winter on the secondary host in partly developed condition Early in the following May the complete their development and deposit unfertilized eggs Th

eggs in this generation are not so numerous as in those preceding Each female lays from 30 to 60

The young which hatch from these eggs are di-morphic in character A part of them are wingless and remain on the douglas fir, while a part are winged and fly back to the primary host. The latter are called *sexuparæ* These that remain on the douglas fir form the spring brood of apterous females on the secondary host, which later lay unfertilized eggs From these, the summer brood on the secondary host hatches The members of the summer brood on the secondary host pass the winter in the immature form and, in their turn, become false stem mothers in the spring following Thus on the douglas fir, there is a complete asexual cycle This cycle on the secondary host, and that previously mentioned on the primary host, may continue indefinitely (Fig. 128).

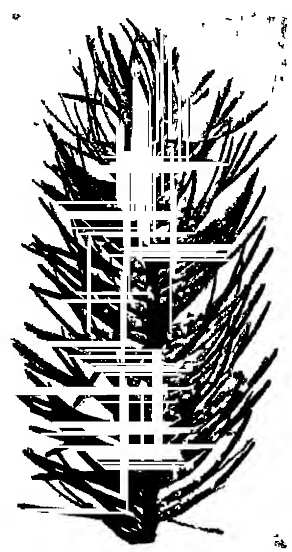


FIG 128 —*Adelges cooleyi* on the needles of douglas fir, a secondary host of this species (*R N Chrystal*)

The *sexuparæ* fly back in early summer to the primary host and settle there They give rise to still other forms, the true males and females. This stage has never been observed in America, but in England, Chrystal (1922) has found them and, doubtless, they occur in this country These sexual forms mate and the females deposit a small number of fertilized eggs on the spruce. These produce the true stem mother or *fundatrix vera*

Thus in adelges there occur three distinct cycles of development the asexual cycle on the primary host, the asexual cycle on the secondary host, and the cycle on both the primary and secondary hosts, in which the sexual forms appear. Apparently, any one of these cycles may continue indefinitely.

No feasible method for controlling adelgids in existing forests has ever been suggested It is possible that forests of the future may be protected from adelgids by the selection of resistant tree varieties On shade and ornamental trees adelgids may be controlled by spraying Because of their covering of woolly

wax, these insects are difficult to kill with a spray. Chrystal has found that on the secondary host they are most susceptible in late winter when they are almost without this covering. This is also true of the young stem mothers on the primary host. On the primary host, sprays are obviously useless when the insects are within the gall.

Almost any strong contact insecticide is effective. Because of their waxy covering, sprays for these insects should be strongly soapy or should contain an oil In England, the following formula for nicotine emulsion has been recommended· ¾ ounce of 90 per cent nicotine, ½ pound of soft soap, and 10 gallons of soft water. The following directions accompany the formula: "Dissolve ½ pound of soap in 4 pints of boiling water, allow the solution to cool and then add ¾ ounce of 90 per cent nicotine. Stir well and keep in a well-corked bottle. To use, take 1 (fluid) ounce of the concentrated solution and make up 1 pint with soft water " This gives a dilution of approximately one part of nicotine to 250 parts of water. Nicotine sulphate at this rate in a strong soap solution would probably give equally good results. Nicotine oleate, the formula of which was given under aphid control, should also give satisfactory control when applied in late winter or very early spring. Miscible oils should also prove satisfactory for sprays or dips

Adelgids on lawn trees may sometimes be effectively controlled by washing the trees thoroughly with a forcible stream of water from the garden hose. Pruning the galls, before they open, from small trees of the primary host may be desirable under certain conditions where other larger host trees are not near by. In forest plantations, the trees are particularly susceptible to injury by adelgids during the first few years after planting For this reason, it is important that adelgid-free planting stock be used Before being set out in plantations, all infested nursery stock should be dipped in one of the spraying solutions mentioned above or fumigated with hydrocyanic acid gas as previously described

In the forest, certain biotic agencies are operating to bring about a natural control. Among these are certain parasites, predatory insects like the coccinellids, the syrphids, or the aphis lions, and predatory mites and spiders In as much as the most susceptible trees are those that are growing under unfavorable conditions, it is apparent that any improvement of growing

conditions will reduce the danger of injury Proper thinning, intelligent drainage, and careful selection of planting sites to suit each species, are some of the practices of good silviculture that will aid indirectly in controlling adelgids

Questions on Literature

1 What are some of the important adelgids in America? In Europe?

2. Where does *Adelges cooleyi* usually pierce the leaf of the secondary host? Into what tissues are the stylets usually inserted?

3 What adelgids are especially injurious to the secondary host?

4 Are any adelgids common to both Europe and America? If so, what are they?

5 What generation in the sexual cycle appears to be most susceptible to weather?

THE SCALE INSECTS

The scale insects, Coccidæ, comprise another family of the Homoptera that includes many dangerous tree insects Because they are so different in habits and appearance from the other Homoptera, and because of their great economic importance, they will be discussed here in a separate section. They are usually regarded as being particularly injurious to shade and orchard trees, although they are really equally dangerous in the forest Their inconspicuousness, coupled with the fact that their work is often supplemented by that of other more conspicuous species, has resulted in a general underestimation of the importance of scales as forest pests. Recently, however, several severe outbreaks in forests have been reported For instance, the black pine-leaf scale, *Aspidiotus pini*, has been responsible for heavy injury in parts of the Lake States and has also been injurious in California forests

The scale insects are very peculiar No one on seeing these creatures for the first time would guess that they were insects. In fact, it is doubtful if on cursory examination a person unfamiliar with them would even regard them as living organisms. They are, for the most part, small to the point of minuteness and many of them appear as tiny scales of wax adhering to the leaves or bark. Others look like small galls, whereas still others appear to be accumulations of granular waxy material, or masses of resinous exudation upon the trees. Although this group includes many important pests, some very useful insects are also members of the family For instance, the lac insects excrete over their

bodies, a resinous material which is an important article of commerce. This material called stic-lac is manufactured into shellac. Before the days of coal-tar dyes the lac insects and other scales, like the cochineal insect, were important in the production of coloring materials

The scale insects are numerous in species and variable in habit and appearance Three groups of the family contain dangerous forest and shade-tree pests These are the armored scales, the tortoise scales, and the mealybugs The life history and habits characteristic of each group are quite different and, therefore, a representative of each one will be discussed

The Oyster-shell Scale.—One of the armored scales, the oyster-shell scale, *Lepidosaphes ulmi*, will be considered first. This insect belongs to the subfamily Diaspini, which is characterized by the scale-like covering beneath which the insect lies. This scale is composed in part of moulted skins and in part of waxy or resinous excretions of the insect.

The oyster-shell scale is well known to almost everyone who works with woody plants. This insect attacks a great variety of fruit trees and deciduous forest trees and shrubs (Fig 129). In the forest, the poplars, willows, and maples are probably the most susceptible trees. This insect is distributed throughout the temperate regions of the world and is either native to America or was introduced in very early colonial days, probably from Europe It now occurs throughout temperate North America from the Atlantic to the Pacific.

The oyster-shell scale is well named It has the general shape of an elongate oyster shell. The full-grown scale is about 1/8 inch in length and brown in color When these insects are abundant, the small branches of the infested trees may be almost completely encrusted with the scales. The male scales are said to be very rare. The exact proportion of males to females has never been determined, but it is so low that according to Griswold (1925) thousands of scales may be examined without finding a male. This suggests that this species usually is reproduced parthenogenetically, although no general acceptance of such an assumption is evidenced in published writings on this insect

In the North, the eggs are deposited in late summer or early autumn and pass through the winter without hatching In the early spring they hatch The time of hatching varies greatly, depending upon the latitude and the season In general, it

corresponds in time to the dropping of the apple blossoms. The young insects creep from beneath the mother scales, by the hundred, and wander about on the bark of the host tree. At this time they may creep upon birds, other insects, or anything else that comes in contact with the trees. In this way, they may be carried from tree to tree, or even from locality to locality.

FIG 129.—A branch of aspen almost completely covered by osyter-shell scale, *Lepidosaphes ulmi.*

After wandering aimlessly about over the bark for some time, the young settle down in a suitable place, insert their mouth parts, and proceed to feed upon the sap of the tree on which they are resting The secretion of the scale then begins. The female scales never move again but live for the remainder of their life beneath the scale As the insect grows, the scale is increased in size so that the body is always entirely covered When mature, the female has lost both legs and eyes She is little

more than a reproductive sack with sucking mouth parts through which the food is drawn The male, on the other hand, undergoes an entirely different type of metamorphosis and after passing through a stage resembling the pupal stage of holometabolous forms, he emerges in the form of a tiny insect with antennæ, compound eyes, two wings, and the mouth parts replaced by a second pair of rudimentary eyes. The male takes no food and is short lived.

FIG 130 —The scurfy scale, *Chionaspis furfura*. (*University of Minnesota*)

By the time the female is full grown, her body is filled with eggs. As she lays them her body shrinks in size, until almost the entire cavity beneath the scale is occupied by eggs and, in consequence, the mother is crowded into a small portion of the anterior part. Shortly after oviposition, the female dies, consequently, by late autumn there are no females alive. The number of eggs deposited by each female varies from 20 to slightly more than 100 In the North, there is only one generation of this insect each year In the South, there are two genera-

tions Where there are two generations, the eggs of the first brood are deposited early and hatch during the month of July

Other important species of armored scales pass through life cycles very similar to that of the oyster-shell scale The scurfy scale, *Chionaspis furfura* (Fig 130), and the pine-leaf scale *Chionaspis pinifoliæ* (Fig 35), both pass the winter in the egg stage and develop in a manner quite comparable to that of the oyster-shell scale Other members of this group pass the winter in a partly grown condition and complete their development in the following spring In some of these scales the eggs hatch within the body of the female, and the young are born alive.

The control of scale insects is very much the same for all species Instead of taking up the question of control in each individual case, scale control in general will be discussed at the end of this section.

Questions on Literature

1 What are some of the armored scales not mentioned here that are dangerous tree pests?

2 What important species of armored scale gives birth to living young?

3 Is there more than one form of oyster-shell scale? If so, what are they and how are they distinguished?

4 How rapidly may a scale insect spread out from a center of infestation?

5 What trees, in addition to those mentioned above, are subject to the attack of the oyster-shell scale?

The Cottony Maple-scale.—The tortoise-scale group is well illustrated by the maple scale, *Pulvinaria vitis* This group of scales are so called because of their tortoise-like form. Some members of this group secrete very little wax and are, therefore, called naked scales, others, like the cottony maple-scale, are naked but excrete wax to form an egg sack; whereas, still others excrete wax in abundance Unlike the armored scales, the legs of many tortoise scales are not reduced to the point of uselessness, at least not until the female becomes filled with eggs They may, therefore, change their location when partly grown The scales of this group are, for the most part, much larger and more conspicuous than the armored scales. Many of them excrete large quantities of honeydew which may coat over the leaves and branches of infested trees. A black fungus that grows in the honeydew usually gives the infested trees a decidedly black appearance, which is often very unsightly.

The cottony maple-scale attacks maples, particularly the soft maple, throughout the range of its host trees and, when abundant, may kill trees Previous to cold weather, the female is fertilized, and she spends the winter in a partly developed stage on the small branches of the host With the arrival of spring, these females complete their growth. When full grown, they are

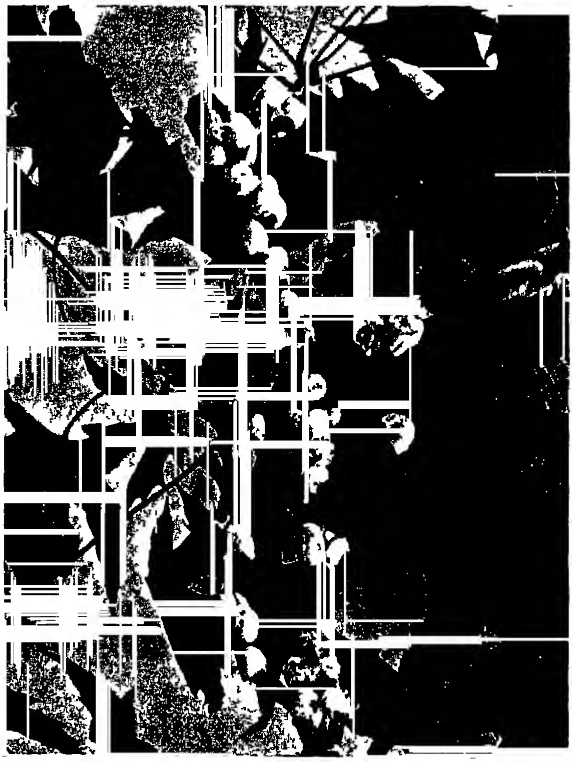


FIG 131 —The cottony maple-scale, *Pulvinaria vitis*, on soft maple (*University of Minnesota*)

large for scale insects, sometimes being considerably over ⅛ inch in length and broadly ovate in form Their color is a dark brown. Full growth is attained early in the summer at which time they begin to lay their eggs The specific name *innumerabilis*, which has sometimes been applied to this species, describes well the fecundity of this insect A comparatively unproductive individual will lay 500 eggs, while some females may produce

several thousand. The biotic potential of such a species is tremendous. If the factors of environmental resistance were reduced, it is obvious that, with such a high potential, this insect would multiply at an almost unbelievable rate.

The high fecundity of this species may be remarkable but it is not the only interesting fact in connection with its reproduction. As in the case of some other members of the tortoise-scale group, the eggs are laid in egg sacks constructed of cotton-like wax A conspicuous, white, cottony mass that is filled with eggs is extruded from beneath the caudal end of each mother scale (Fig. 131) These white masses stand out prominently against the blackened bark of the trees and naturally attract much attention Some other species of the tortoise-scale group, instead of depositing their eggs in egg sacks as does this species, lay them beneath their arched bodies; whereas still others produce living young.

The tiny young scales leave the egg sacks in July or August and make their way to the leaves There they settle down and feed until fall. Most of them locate on the lower side of the leaves along the large veins. The males develop much more rapidly than the females and emerge as winged adults in late summer or fall At that time mating takes place even though the females are not fully developed After fertilization and before the leaves fall in the autumn, the females migrate from the leaves and make their way back to the twigs and small branches where they pass the winter, complete their development, lay their eggs, and die

Questions on Literature

1 What other names are sometimes applied to the tortoise-scale group?

2 What are some of the species of tortoise scales, other than the cottony maple-scale, that are of economic importance?

3 What plants other than maples are said to be attacked by the cottony maple-scale?

4 How is the scale carried from tree to tree?

5 In what part of the United States is the cottony maple-scale most abundant and injurious?

The European Elm-scale.—The European elm-scale, *Gossyparia spuria,* is a member of another group of scale insects, the mealybugs The members of this group are best known as pests of greenhouse plants but some of them are injurious to trees, particularly in the South. Even in the North, however, some of

our most injurious scale insects belong to this subfamily. The mealybugs excrete a powdery wax, which covers their bodies This flour-like excretion gives them their common name.

The European elm-scale is one of the most dangerous tree pests of all the mealybugs This insect is one of our foreign guests which we could well do without. It was first discovered in this country in New York State in 1884, but it had apparently been established for some time previous to that date. In 1894 it was reported from California, and it is now known to be widely distributed throughout the United States and Canada Wherever it makes its way, it becomes a troublesome and dangerous pest of elms. So far, it has not become a forest pest, and for the most part it is confined to shade trees in cities and towns If it should ever become established in a forest, it quite probably would be as serious a pest as it is in the towns. Great care should be exercised to prevent the introduction of this scale into forest areas.

When this pest first appears in a locality, it is usually very injurious It attacks all species of elm and becomes abundant. Heavily infested trees are liable to succumb If the trees are not killed in the early years of the outbreak, however, they are likely to survive. Perhaps the trees are able to build up a resistance to the pest, or perhaps the scale is brought under control by its natural enemies This will probably be the history of the insect if it gets into a forest. Natural enemies will control it But while a new biotic balance is being attained, much injury may be expected to result.

The chief way in which new infestations may occur is by transporting the pest to new localities upon infested nursery stock. The overwintering scales may easily be carried from place to place in this way The other means of dispersal (on wind-blown leaves, on birds or insects, by ants, or by the scales creeping from tree to tree) are slow and account only for local, gradual spread.

The body of the European elm scale is ovate in form In the second stage this species excretes a powdery wax like the other mealybugs The third-stage females are brown in color and without any dorsal covering. They do, however, excrete a white waxy fringe which curves upward from the ventral side and partly encloses the body (Fig. 132) This is called the semi-cocoon. The males, between the second stage and the adult, are enclosed in white, waxy cocoons.

The life cycle of this insect is, in general, similar to that of the other scales discussed above The winter is passed on the branches of host trees in the second instar Their covering of powdery wax serves to protect them to some degree against both excessive desiccation and excessive moisture Very early in the spring, or even in late winter, the males moult to the third stage and spin their waxy cocoons After completing their

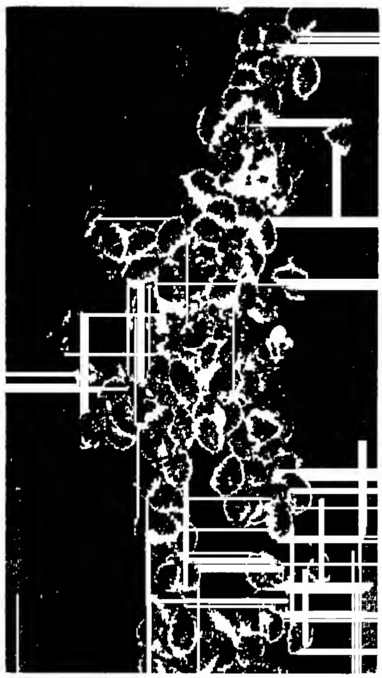


FIG 132 —A mass of female, European elm-scales in the third stage Note the semicocoon surrounding each insect (*Bureau of Entomology, U S. Dept. Agr*)

cocoons, they moult again This fourth stage, the prepupal, is a quiescent stage within the cocoon. In the course of a week or more the prepupa moults again. It is then a pupa After another quiescent period the adult males emerge from the cocoon The first males to emerge are wingless, the later emergents are winged Between these two extremes are insects with all stages of wing development.

In the meantime the females have also been undergoing a certain change About the time that the adult males are ready to emerge from their cocoons, the females moult for the last time

The males emerge and mating takes place. The fertilized females then seek out a suitable location, usually on the under side of a branch, and settle down for the last time. They then begin to excrete the conspicuous fringe of white wax, the semicocoon, that partly envelops the body. During this third period of her life the female excretes large quantities of honeydew which drops onto the branches, and later onto the foliage, and upon the ground beneath the trees, and covers everything within range, with a sticky coating. In this sweet material a black fungus grows, so that before long the infested trees assume an inky-black appearance

By late spring, the females are fully grown and have completed their semicocoons They are then ready to lay their eggs The egg-laying period of most insects is brief but this insect takes her time in performing this important process. Oviposition may last for several months. The eggs are held in the body of the mother until they are about ready to hatch at which time they are expelled. The vulva opens ventrally so that the eggs are deposited beneath the mother's body where they are protected until hatching has been accomplished Each female lays a large number of eggs, although by no means as many as does the cottony maple-scale

In less than an hour after the eggs are laid the nymphs hatch and leave the mother. They migrate to the leaves where they settle down to feed. During this stage little wax is excreted, and except for the pubescence of the leaves, they are without protection. Some six weeks after hatching, they moult for the first time. In this stage a powdery wax covers the body. With the approach of autumn, most of the young scales move from the leaves and locate themselves upon the branches and trunk. Those that fail to do this drop with the leaves and most of them probably starve Some are said to creep up the trunks of convenient trees, where they establish themselves Thus the insect may be spread from tree to tree on wind-blown leaves

Questions on Literature

1. What are some of the other mealybugs that are injurious to trees?
2. Are the mealybugs more abundant and injurious in temperate or tropical countries?
3 Why is the European elm-scale confined for the most part to cities or the neighborhood of cities?
4 What is the relation of ants to the European elm-scale and similar mealybugs?

Control of Scale Insects.—Scale insects are very difficult to control even on shade and nursery trees For that reason, it is particularly important that every possible precaution be taken to prevent the introduction of scales into uninfested localities Planting stock should be carefully inspected and if scale infestation is found the stock should be rejected, because no treatment of infested stock will give perfect results

When once infested with scales, a forest will always remain infested and only by means of natural factors can these pests be held in check. Fortunately, there are many valuable agencies of natural control. Unfavorable weather conditions, for example, heavy washing rains during the migration of the young scales, may reduce the numbers of the insects materially In 1925, heavy rains during June checked a dangerous infestation of the black pine-leaf scale, *Aspidiotus pini*, in the jack-pine region of Minnesota

Like most other insects, competition among themselves appears to be a control factor, in some cases When the suitable parts of a tree become heavily encrusted with scales, the fecundity of the individual is apparently much reduced, because of food shortage In still more severe cases, the death of leaves or twigs upon which the scales are feeding may bring about an acute food shortage and ultimate starvation for many scales.

Predaceous insects, like the ladybird beetles, feed upon scales. The adults and the larvæ of these beetles both participate in this valuable work The larvæ of the lace-wing flies, Chrysopidæ, are also important enemies of scales. Among the most important of the predatory groups that feed upon scales are the mites All mites that are observed under or near scales are not necessarily predaceous Some of them are scavengers but many of them, like *Hemisarcoptes malus*, are important predatory forms This particular species feeds upon the oyster-shell and San José scales and is very important in controlling these pests Tothill (1918) reports that this is by far the most important agency of control of the oyster-shell scale in eastern Canada. (Fig 148)

Certain small hymenopterous parasites are also important in keeping scale insects in check. *Aphelinus mutilaspidis* is one of the important parasites of the oyster-shell scale.

In some cases, it has been possible to regulate the activities of some of these biotic factors of control, and thus use them directly against a specific pest For instance *Rodolia* (*Vedalia*)

cardinalis, a coccinellid, has been introduced into California to control the cottony cushion scale, *Icerya purchasi*, and has proved very effective. The beetles have been reared and liberated where they were most needed. Tothill suggests that Hemisarcoptes might be handled in a similar manner to control the oyster-shell scale. But as we have seen in a previous chapter, we are not yet able to make full use of these biotic factors of environmental resistance in directed control work.

Chemical methods of direct control must be resorted to. Spraying and fumigating are the two most important means of coccid control that are at our disposal These methods are not, of course, applicable in the forest, but they can be used to advantage on nursery stock. Fumigation of nursery stock with hydrocyanic acid gas is, perhaps, the best method available for treating scale-infested materials. If properly done, this treatment will give good control for practically all scales.

Spraying of shade and other ornamental trees with a contact insecticide gives reasonably good control, but in most instances repeated applications are necessary The small armored scales are susceptible to lime sulphur at the rate of 1 part to 9 parts of water. This material should be applied in the spring just as the trees are beginning the season's activity. This material has not proved satisfactory for the oyster-shell scale and some other closely related forms. Neither is it effective upon large scales like the cottony maple-scale and the European elm-scale. For these scales a dormant spray of a miscible oil is generally used Spraying with nicotine extract at the rate of 1 part of nicotine to 500 parts of soapy water will kill all the different species of young scales. Such a spray repeated once a week, during the hatching period, is an excellent method of control

A simple method that has proved satisfactory in the control of some of the large scales, like the cottony maple-scale and the European elm-scale, is to wash the trees with a hard stream of water. On small trees this can be accomplished by use of the garden hose. On larger trees, a larger hose and higher pressure is necessary. On the whole, however, this is not so satisfactory a method as spraying with miscible oil.

CHAPTER XVI

INSECTIVOROUS PARASITES

The part that parasites and predators play in environmental resistance has already been seen in Chap. IV, and in Chaps. VI and IX is explained how they may be used either directly or indirectly in the control of insect pests Furthermore, it has been seen that parasites and predators are to be found in many groups in the animal kingdom In this chapter, a few representatives of some of these groups will be discussed.

ENTOMOPHAGOUS MICRO-ORGANISMS

Certain members of each of the different groups of micro-organisms attack insects Some of the types of insect diseases caused by them are bacterial diseases, fungous diseases, and protozoan diseases. It is generally believed that the filterable-virus diseases are also caused by micro-organisms, but these organisms have never been isolated in connection with any filterable-virus disease. The part played by some of these organisms in parasitizing insects will now be considered. Examples of bacterial, fungous, and the polyhedral type of filterable-virus diseases will be cited as illustrations. Because so little is known concerning the part played by protozoan diseases in connection with insect activities, no examples of these will be discussed

Bacterial Diseases.—References to bacterial diseases of insects are exceedingly common in entomological literature In many instances, the diseases mentioned were undoubtedly caused by bacteria, but, owing to the difficulties attendant upon the conclusive identification of the causative organisms and to the general unfamiliarity of entomologists with bacteriological technique, many incorrect determinations have resulted

Epidemics of bacterial insect diseases usually occur only when the host is extremely abundant This is probably because they are, for the most part, infectious in character, and it is only when the population of the host is quite dense, with the resultant fre-

quent contact between the individual insects, that conditions for infection are at their best Some of the most serious bacterial diseases of insects gain entrance into the digestive tract along with the food. There they multiply and attack the host tissues The method of entrance in many instances is unknown. These disease organisms may attack insects in any stage, but those that we now consider as being most important are the cause of larval diseases

The symptoms of the diseases vary somewhat. As a rule, however, the first symptom appears to be a loss of appetite on the part of the affected larvæ. Later, these larvæ cease to eat and finally die Previous to and following death, changes in color usually occur Often this color change is first indicated by a fading and yellowing of the natural larval colors Later, usually after death, the larvæ become much darkened. After death has occurred, a rapid disintegration of the internal tissues takes place until finally the skin is filled with a dark liquified material. Frequently, the insects suffering from one of these parasitic diseases will continue to hang to the plant on which they were feeding, even after death

Outbreaks of bacterial diseases are frequently correlated with weather conditions. Cool, moist weather followed by a warm period is, in most cases, conducive to epidemics This suggests the probability that cool, moist weather is favorable for infection, and that warm weather is conducive to the rapid growth of the organism Perhaps, under comparatively cool conditions, the growth of the bacteria may be sufficiently slow to permit the continued development of the infected larvæ, but this is only conjecture.

In 1915 an interesting and perhaps valuable bacterial parasite of the gypsy moth was unintentionally shipped into this country from Japan Glaser (1918) described the symptoms and characteristics of the disease caused by this bacteria and determined, to his own satisfaction, that it was not previously present in America. This organism, described as *Streptococcus disparis*, will serve well as an illustration of a bacterial parasite.

This is one of the parasites that gains entrance into the body of its host, along with ingested food. The parasite lives and multiplies in the insect's intestinal tract. The first effect upon infected larvæ is to produce a violent form of diarrhea accompanied by loss of appetite. In the early stages of the disease,

the organism is confined to the alimentary canal, but as the disease progresses the muscle tissues also become involved Finally the affected larvæ cease to eat, lose all muscular coordination, and die. After death they usually continue to hang by their prolegs. Then the tissues rapidly disintegrate During the early stages of the disease the larvæ contaminate the foliage on which they are living, thus passing on the parasite to other larvæ that eat the contaminated leaves. In this way the disease spreads rapidly especially when the gypsy-moth larvæ are numerous

Fungous Diseases.—Entomophagous fungi are not at all uncommon among insects and sometimes, as in the case of the chinch-bug disease mentioned in Chap. VI, may be largely responsible for checking an outbreak As we have previously pointed out, the direct use of these organisms in control is made very difficult, because their effectiveness depends upon certain favorable weather conditions.

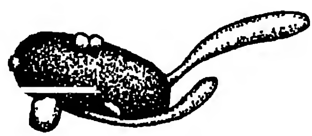


Fig 133 —A larch-sawfly cocoon on which is growing the entomophagous fungus, *Isaria farinosa*

Most of the studies of these fungi that have been made have not been concerned with forest insects Hewitt (1912), however, in connection with his study of the larch sawfly, has investigated one of these diseases He found that this disease, *Isaria farinosa*, in some localities both in England and Canada, was responsible for the death of a very large percentage of the cocooned larvæ. Hewitt has shown that the larvæ become infected after dropping from the trees in search of suitable hibernating quarters. The Isaria fungus lives, as does a saprophyte, on the moss beneath the trees and its spores are capable of infecting larvæ that crawl over the infected moss. The effectiveness of the disease depends upon the abundance of saprophytic growth, which in turn depends largely upon moisture conditions (Fig 133) After having been infected by the fungus, the larvæ proceed normally to spin their cocoons, after which they succumb to the disease The external appearance of the larvæ changes They lose their greenish color, and by the time of death, become pinkish white Finally, the larvæ are completely mummified within the cocoon

The growth of this fungus within the body of the host was not studied by Hewitt, and hence, we do not know exactly what the

internal effects were. It is probable, however, that they may be similar to the effects of other closely related diseases. In some of these, yeast-like bodies appear in the blood a few days after infection (Speare, 1920). These cells multiply rapidly, increasing in number until the blood takes on a milky appearance. Finally, the blood becomes so filled with these blastocysts, as they are called, that circulation ceases and the larvæ finally die. When the blood ceases to circulate, the blastocysts, although they continue to form, do not break off from the parent cell, with the result that colonies of individuals are formed that later become resting spore masses. The saprophytic growth on the moss, mentioned above, presumably arises from these spores. When the nutriment in the blood is exhausted, other tissues are attacked until all the organs are destroyed.

There is some difference of opinion concerning the manner in which entomophagous fungi grow within the insect's body. Some authorities claim that the growth resembles branching hyphæ. Speare (1920) maintains that, although this may be true in some diseases it is not the case with the species of Isaria, Sorosporella, and Botrytis that he has studied. These organisms, he states, multiply by the division of yeast-like cells as described above. Furthermore, he points out that this method of multiplication "seems especially well adapted for reproduction in a liquid menstruum such as insect blood, the circulation of which carries them to all parts of the body cavity and continually supplies them with fresh nutriment."

Polyhedral Diseases.—The consideration of an exceedingly interesting group of insect diseases that, judging by their reactions, are supposedly caused by organisms will now be taken up. The organisms, however, have never been isolated. These diseases of insects are very similar to some of the most dreaded diseases of man and other mammals; hydrophobia, smallpox, and trachoma, for instance. They are characterized by the presence of granular bodies in the blood and in certain tissues. In insects, these bodies are called "polyhedra." The nature of these polyhedral bodies has long been a point of controversy; some maintain that they are chemical by-products of the disease organisms, whereas others claim that they represent a stage in the life cycle of the disease organism. Which of these opposing views is correct has not yet been settled, but experiments have proved that the virus of the polyhedral diseases is

capable of passing through Berkfeld *N* candles, through which the granular polyhedral bodies fail to pass.

Although their true nature is not known, these diseases are among the most effective parasites in the natural checking of outbreaks of certain lepidopterous insects. Up to the present time, the polyhedral diseases have never been found attacking insects other than representatives of the Lepidoptera. Among the most important of these diseases, in America, is the wilt disease of the gypsy moth and the wilt of the tent caterpillar. It is possible that these may not be two distinct diseases, but up to the present they have been so regarded

The gypsy-moth wilt is apparently identical with the *Wipfelkrankheit* of the European nun moth and was not present in America previous to 1900 (Glaser, 1915). Presumably it was accidentally introduced into this country long after the gypsy moth became firmly established Now it is distributed throughout the infested region where it is of material aid in keeping the pest in check.

Like the bacterial diseases, the wilt disease is infectious. It gains entrance into the body of the insect through the mouth with ingested food After becoming established within the insect, it attacks and kills the blood cells and certain other tissues, with the result that the caterpillar usually succumbs. In certain instances, however, the insect is able to survive, complete its development, emerge as a moth, and reproduce itself without showing any external indications of the presence of the disease. In such instances, the infection may be passed on through the egg to the progeny Because of the presence of these chronic carriers, one can never be sure that the disease is not present, even though the caterpillars in a locality may appear to be healthy. Under high temperature conditions, these chronic cases may become acute with the result that the host will be killed and an epidemic will be started among the larvæ.

Epidemics of wilt have been especially common whenever the gypsy moth has become very abundant and stripped most of the foliage from the trees on which they were feeding. Under such conditions, the larvæ are exposed to much higher temperatures than normal, because the direct rays of the sun can shine through the crowns of the trees upon them. When once the disease breaks out, the mortality is exceedingly great. Sometimes it

amounts almost to extinction In Europe, the outbreaks of this disease among the nun-moth caterpillars have, likewise, frequently resulted in almost the complete extinction of the host.

The larvæ, when infected with the wilt disease, first become sluggish and then stop eating. Before dying they have a tendency to climb high up in the trees and, after death, they remain there hanging by their prolegs The tissues of the body become darkened, decomposed, and liquefied. The larvæ hang flaccid until finally they are completely disintegrated, and they then dry upon the tree. These dried smears that were once larvæ remain infectious for a long time, and it is thought probable that plants on which nun- or gypsy-moth larvæ had died may have been shipped from Europe into this country, thus bringing about the inoculation of the gypsy moth in America

PARASITIC INSECTS

Of all the groups of parasites that attack insects, the parasitic insects have received most attention from entomologists. Parasitic insects do not constitute a phylogenetic unit but are to be found in many different orders of insects, and in widely divergent families within those orders The great majority of the most valuable species belong either to the Hymenoptera or the Diptera.

General Characteristics.—The adult stages of parasitic insects vary greatly in form, but the larval stages are very similar in appearance. The larvæ are practically all legless grubs, maggot-like in form Most of them are able to move about only with difficulty The mouth parts are, without exception, much reduced or in some instances they may be vestigial Thus, they are specialized for a mode of life which is characterized by an abundance of easily obtainable food, and they illustrate the condition that is called specialization by reduction of parts

The adults, on the other hand, are specialized to insure successful infestation of the host This is accomplished in a number of different ways by the parasites belonging to the various groups The Sarcophagidæ and some of the Tachinidæ are larviparous This adaptation, by eliminating the helpless egg stage, increases the probability of successful entrance of the parasite into the host Those Tachinidæ that are not larviparous stick their eggs firmly to the body of the host Most of the Ichneumonoidea are provided with an elongate ovipositor which they thrust either

into the host or into its cocoon, and there deposit their eggs. Others of this same group are said to place their eggs in the galleries of wood borers, and the larvæ when they hatch creep along the gallery until they find the host. *Megarhyssa* (*Thalessa*) *lunator* (Fig 30), which is one of the largest of the Ichneumonidæ and a parasite upon the pigeon tremex, *Tremex columba*, is said to have this habit But in view of the fact that the borers of the family Siricidæ, of which the pigeon tremex is a member, pack their burrows full of frass as they progress, the eggs of the parasite

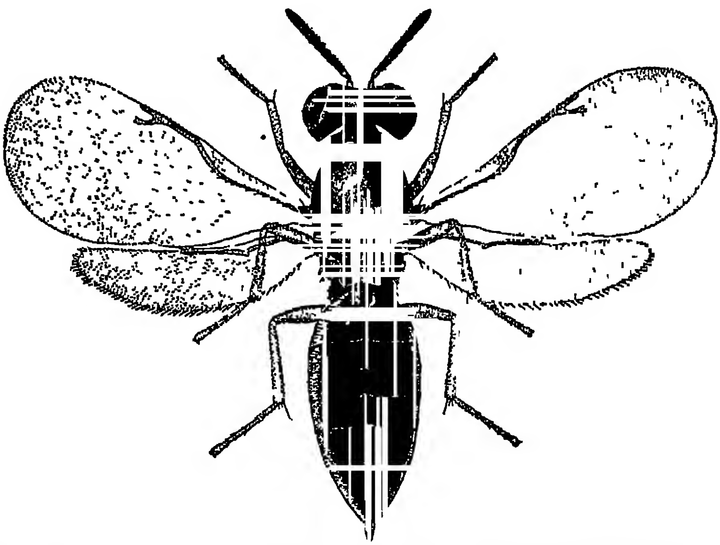


FIG 134 —A hyperparasite, *Dibrachys boucheanus* (*Bureau of Entomology, U S Dept Agr*)

must be placed very near the host, if not actually on its body. The large ichneumonids are remarkable for the fact that they are able to drill through solid wood, in order to place their eggs in a favorable position in or near their host The Chalcidoidea are smaller than most of the ichneumonids, and usually deposit their eggs within the body of their host, although some species of this group, as well as some of the other Hymenoptera, are able to feed externally In the case of external feeders, the host usually dies soon after it is attacked or, in some instances, is killed by the adult parasite at the time of oviposition (Graham, 1918) The smallest of the hymenopterous parasites are the Proctotrupoidea Many of these tiny insects parasitize eggs, whereas others are

larval parasites As a rule, if they are larval parasites, they attack only small insects

Parasitic insects are sometimes limited to a single host These are called "specific parasites" Others are able to attack a number of closely related species, whereas still others are general parasites, because they are able to attack and parasitize a great many different species.

Insects that are parasitic upon other insects are often regarded as being always beneficial to man's interests, in as much as they reduce the number of injurious species Such a generalization is not entirely safe, however, for there are parasites that attack either predaceous insects or insects useful to man in other ways Thus, some insect parasites may be injurious Those species that attack and parasitize other parasites are called secondary or hyperparasites (Fig 134) Hyperparasitism is known to occur to the third, fourth, and, possibly, fifth degree. This force reduces the effectiveness of parasites in holding down insect numbers and adds to the complexity of the part played by parasites in environmental resistance (Fig 135).

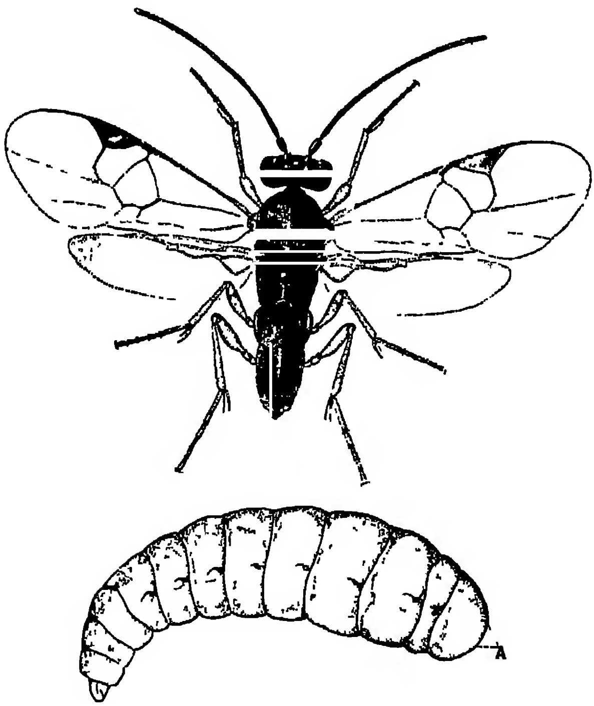
FIG. 135 —A parasite attacking a predator The larva of an ichneumon parasite attached to a spider (*Bureau of Entomology, U S Dept Agr*)

The order Hymenoptera contains more species of parasites than any other insect order. In fact, three superfamilies are made up almost entirely of parasites and are often given the group name, parasitic Hymenoptera These three superfamilies are the Ichneumonoidea, the Chalcidoidea, and the Proctotrupoidea. A representative from each of the first two of these groups will be discussed. Next to the Hymenoptera in number of parasite species comes the Diptera One important representative of this order will be discussed

The Ichneumonids.—One of the ichneumonids about which much has been written in recent years is *Apanteles melanoscelus*, an introduced parasite of the gypsy moth in New England (Fig 136). This is a small black insect, about 3 millimeters in length

It was introduced into this country from Europe, where it is one of the most effective of the natural enemies of the gypsy moth.

This insect possesses many characteristics that, from the viewpoint of man, are desirable in a parasite Its biotic potential is exceedingly high. Crossman (1922) states that it is safe to assume that each female is capable of depositing in the neighborhood of 1,000 eggs Although no data are given concerning the



'IG 136—Adult and larva of *Apanteles melanoscelus* (*Bureau of Entomology, U S Dept Agr*)

ex ratio, he infers that the sexes are approximately evenly ivided or that perhaps there may be an excess of females over ıales In as much as this species is not polyembryonic, the iotic potential would be in the neighborhood of 500 for each eneration The life history of Apanteles is perfectly synchroized with that of the gypsy moth It is active and persistent in s attempts to place an egg in its host and, under laboratory onditions, it will parasitize one larva after another for periods of 'om 30 minutes to 1 hour, as rapidly as they can be presented.

Still another advantage that this parasite possesses is its ability to parasitize a number of small hairy caterpillars. In Europe, it is reported as a parasite of only the gypsy moth and the satin moth. In America, however, it attacks the tent caterpillar, and several tussock moths as well as the gypsy moth and the satin moth This ability to transfer its activities to other species makes it possible for this parasite to maintain itself in spite of the periodical scarcity of gypsy-moth larvæ.

Unfortunately, however, this insect suffers greatly from the attack of secondary parasites and ants, especially while it is in the overwintering stage. These reduce its numbers materially thus preventing it from being as effective in checking the gypsy moth as it might otherwise be Crossman (1922) reports a maximum of 10 per cent secondary parasitism in the first generation and 75 per cent for the second or overwintering generation. But in spite of this high percentage of loss, a simple calculation will indicate that factors of environmental resistance, other than secondary parasites, are operating against Apanteles and are playing an important part in reducing the numbers of this parasite. Otherwise, with its high potential, it would be able to overtake and exterminate its host in a very few years after becoming established in a locality, in spite of its secondary parasites. One of these resistance factors is, undoubtedly, the untimely death of many hosts, from other causes, before the parasites within them have reached full growth; for, obviously, when the host dies the parasite within it must die also

The life history of *Apanteles melanoscelus* is similar in all but a few respects to that of other ichneumonids (Crossman, 1922) Perhaps the most unusual feature is the fact that two generations of the parasite occur during the larval period of the host. Adults of the first generation emerge from their overwintering cocoons at about the time the gypsy-moth eggs are hatching In the average season, this begins about the middle of May. This emergence extends over a period of about 3 weeks The female parasites are able to begin oviposition very soon after they emerge

The act of oviposition requires only a second. The parasite comes up to a host larva, quickly inserts her ovipositor, lays a single egg, and withdraws her ovipositor in an almost unbelievably short space of time. Sometimes the caterpillar may struggle about and even may fall from the tree in its attempts to

avoid the attacking parasite, but, according to Crossman, on whose statements this account is based, these attempts at evasion are usually futile

In from 48 to 72 hours the eggs hatch, and the larvæ make their way to the dorsal part of the posterior end of the body cavity Here they usually remain until they are ready to emerge They feed upon the fat cells and lymph of the host until they have passed through two instars. The third instar larvæ, of this first generation, leave the host in from 7 to 13 days after the time they were inserted as eggs—a rather short period of development even for an insect

The emerging larvæ spin their pale yellowish cocoons near the place at which they emerge, and there transform to the pupal stage (Fig 137) A period of from 5 to 9 days are required before the adults emerge Thus, the entire first generation cycle may only require 14 days, although some individuals may require as long as 25 days

Fig 137 —Cocoons of *Apanteles melanoscelus* (*Bureau of Entomology, U S Dept Agr*)

In the meantime, most of the gypsy-moth larvæ that escaped parasitization, or other mishaps, have only reached the third instar and still are sufficiently small in size to provide suitable host material for the second generation of Apanteles The few, however, which have passed beyond the third instar are fortunate, for their larger size and longer hair will make them much less susceptible to attack than are their smaller brothers

Oviposition begins soon after the adult parasites emerge. The larvæ of the second generation develop more deliberately than those of the first. They require from 13 to 21 days to reach the third instar or almost twice as long as the time required in the first generation The third instar larvæ of the second generation spin cocoons that differ somewhat from those of the first genera-

tion They are a trifle heavier and are a sulphur-like yellow in color Within these cocoons the larvæ pass the winter The following spring, about the time the first gypsy-moth eggs hatch, these overwintering larvæ, if they have survived the attacks of their enemies, transform to the pupal stage and, shortly thereafter, emerge as adults ready to start another spring generation of parasites.

The Chalcids.—The superfamily Chalcidoidea of the Hymenoptera contains a tremendously large number of species which differ more or less from one another in habit. Some of them are external or ectoparasites (Figs. 138, 139), whereas others live within the host and are called "endoparasites" Some of them have a number of generations during a season, whereas others may have only one or two Some are confined to a single host Others are general

FIG 138

FIG 139

FIG 138 —The larvæ of *Eurytoma pissodis*, an ectoparasite of the white-pine weevil

FIG 139 —Pupæ of the chalcid, *Eurytoma pissodis*

parasites They are all rather small in size and are usually black or iridescent in color

The complete life histories of very few American species attacking forest insects have been studied in detail. One species, however, was studied by Hewitt (1912) which will serve well as an illustration of the chalcidoid group. This happens to be one of the Pteromelidæ, *Coelopisthia nematicida*, and is an external parasite of the prepupal stage of the larch sawfly. Hewitt considers it to be one of the most effective of the larch sawfly parasites.

It is known to be distributed throughout the eastern part of the United States and Canada wherever the larch sawfly occurs, and

in all probability it is to be found throughout the entire range of the sawfly in America

The winter is passed in the larval stage within the cocoon of the sawfly The adults emerge in May or early June while many of the sawflies are still in the prepupal stage. These adults are very small, black insects about 2 millimeters in length They immediately seek out cocoons containing healthy prepupæ and deposit their eggs (Fig. 140). The oviposition of this insect is very different from that of Apanteles The female, with deliberation, thrusts her ovipositor through the cocoon that contains her victim, and there she remains almost motionless for a long time Hewitt observed one female which remained with her ovipositor inserted into the cocoon for a period of 1½ hours, and later, after a rest of 20 minutes, again inserted her ovipositor, this time remaining in the oviposition position for almost an hour. The eggs hatch in about 3 days

FIG 140 —*Coelopisthia nematicida*, a chalcidoid parasite of the larch sawfly, laying her eggs in a sawfly cocoon (*Entomological Branch, Can Dept Agr*)

The larvæ of this parasite, like the adults, are very small and as a result it is possible for a number of them to develop on a single sawfly prepupa It is not at all uncommon to find from 50 to 75 of these parasites feeding within a single sawfly cocoon. It is probable that a single female may lay her entire quota of eggs in one or two cocoons, although we cannot be sure, for no data are available on this point

The parasitized prepupa appears to be stupefied or dead even before the parasite eggs have hatched Later on, after the larval parasites have begun feeding upon the blood and other tissues, the host is obviously dead Before the parasite larvæ have fully developed the host is almost entirely decomposed This condition is very similar to that observed in the bee-moth larvæ parasitized by a closely related pteromelid (Graham, 1918). In that instance the host larvæ were killed by the parasite at the time of oviposition

The larval stage requires about 12 days for its completion. When fully developed, they transform to the pupal stage within the cocoon of the host and later to the adult stage. The adults cut their way through the cocoon and emerge to seek new hosts About 23 days is required for development under ideal conditions This period is probably considerably lengthened under

the cool conditions that exist in the tamarack swamps. On the basis of laboratory experiments, Hewitt concludes that 6 broods may be developed during a season This may be possible under especially favorable conditions, but it is doubtful if this many generations occur in nature.

On first thought, it would appear that an insect of this sort, with a series of short generations, would be limited in its effectiveness as a parasite by the unavailability of suitable host material at certain seasons Although this is true to a certain degree, it is not such an important limiting factor as might be expected. This is because sawfly prepupæ are available at practically any time during the growing season The period of greatest scarcity is during June, but even at that time many that have been delayed in emergence can be found Thus, the parasites can obtain suitable host material at almost any season.

Questions on Literature

1. How may the Ichneumonoidea be distinguished from the Chalcidoidea and the Proctotrupoidea?
2. How is the fact explained that only males of certain parasites emerge from certain small larvæ?
3. What do the adult hymenopterous parasites feed upon?
4. Is there any relation between the length of life and the rate of activity of parasitic Hymenoptera?
5. What is the effect of temperature and light upon the activity of hymenopterous parasites?

The Tachinids.—Among the parasitic Diptera the various species of the family Tachinidæ, are probably the most valuable destroyers of forest pests Like other groups of parasites, however, they are not all beneficial for some parasitize beneficial insects (Collins and Hood, 1920) The habits of the tachinid parasites vary considerably. Some of them are oviparous whereas some are larviparous. The oviparous species usually glue their eggs tightly to the body of the host to prevent their being rubbed off before they hatch The larvæ in those species that are larviparous are either deposited on the body of the host or are inserted by means of the larvipositor within the host's body

One of the imported tachinid parasites of the gypsy moth that has become firmly established in America is *Compsilura concinnata.* It attacks not only the gypsy moth but also the browntail moth, the fall webworm, the white-marked tussock-moth,

the forest tent-caterpillar, and many other native insects (Fig. 141). In fact, if it were not for its ability to adopt these new hosts when introduced into this country, it could not have become established here. Since its establishment it is said to have exercised a decided controlling influence upon some of our native pests as well as upon the foreign gypsy and brown-tail moths (Culver, 1919). It has also played an important part in the control of a more recently introduced European pest, the satin moth

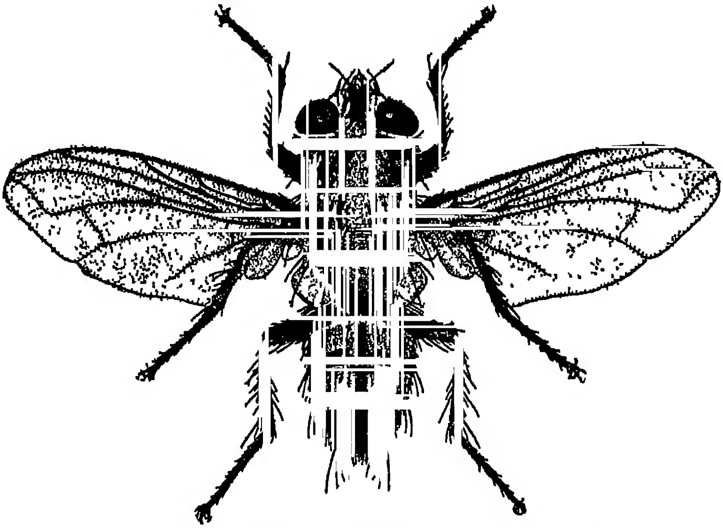


FIG 141 —The adult of *Compsilura concinnata*, an imported tachinid parasite of the gypsy and brown-tail moths (*Bureau of Entomology, U S Dept Agr*)

Compsilura is widely distributed throughout the parts of Europe where the brown-tail moth is found. It has been introduced into America from no less than 10 different European countries and possibly from Japan. From this we are justified in assuming that it is a fairly common parasite in its native lands. It is a rather large, robust, hairy fly about 7 millimeters in length. Its coloring is a combination of black and white which gives the insect a gray appearance.

Compsilura is one of those larviparous tachinids that place their larvæ within the body of the host In parasitizing its host the adult female darts quickly at a near-by caterpillar, pierces the skin with a strongly chitinized piercing organ, inserts its larvipositor, and deposits a larva before the host insect can escape

The larvæ, according to Culver, are usually inserted into the intestine; later they attach themselves, by means of anal hooks, to some part of the tracheal system, often near a spiracle There-after, oxygen is obtained from the tracheal system of the host through the anal spiracles which are pushed tightly backward against the place of attachment Thus, the caudal end of the body is attached while the cephalic end lies free within the body cavity of the host

At the end of the third instar, the larvæ, then being full grown, leave the host for pupation The pupal stage may be passed in bark crevices, in the webs of some host like the tent caterpillar or

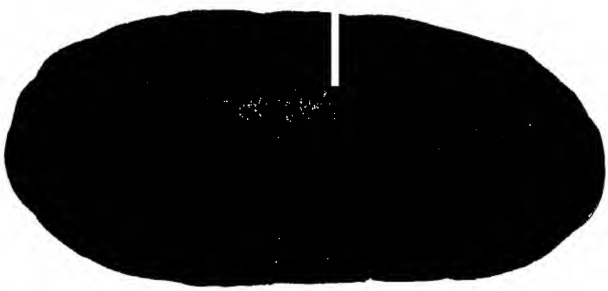


FIG 142—Puparium of the tachinid fly, *Compsilura concinnata* (*Bureau of Entomology, U S Dept Agr*)

the brown-tail moth, or in the surface layers of the soil. As is the case with most of the other Diptera, Compsilura pupæ are enclosed in puparia and not in cocoons. A puparium is the dry, brown, larval skin of the last instar larva (Fig 142)

Compsilura concinnata is active from the beginning of May to the last of October During this period, they pass through three, somewhat over-lapping, generations The first adults that emerge in the spring must, as a rule, depend for host material upon caterpillars of species that overwinter in the larval stage. One such species is the brown-tail moth A little later, in May and June, caterpillars that have hatched from overwintering eggs become available. Among these are the gypsy moths and the tent caterpillars. These insects serve as hosts for the over-wintering generation of the parasite The second-generation adults appear in late June and July They find a great variety of hosts available (Webber and Schaffner, 1926) The third-generation adults of Compsilura emerge in August and September

At that time, comparatively few host species are available Doubtless, this condition limits the number of the parasites

From the preceding discussion it is evident that the host relations of this parasite are exceedingly important in determining its effectiveness in insect control. If secondary hosts are present in adequate numbers to make possible the maintenance of correspondingly large numbers of the parasite, it will be effective If at any time during the active season the necessary supply of secondary hosts should fail, then the numbers of the parasite would be so reduced that it might not be effective at other seasons even when hosts were abundant. The critical period for Compsilura appears to be during the third, or overwintering, generation.

Questions on Literature

1 What other tachinid parasites have been introduced into America for the control of the gypsy moth?

2 Are most species of tachinid flies general or specific parasites?

3 What are some of the more important hosts of the third generation of *Compsilura concinnata?*

4 What has been the effect of Compsilura upon native parasites?

5 Why is this parasite more effective than some of the other tachinids?

6 What is the effect of temperature upon the development of Compsilura?

CHAPTER XVII

INSECTIVOROUS PREDATORS

It has already been seen that representatives of insectivorous predators are to be found in many different groups of animals To discuss all of these would be far beyond the scope of this book. Consideration, therefore, will be confined to some of the more important of them

PREDATORY INSECTS

It is impossible to say which of the insectivorous predators are the most valuable from man's viewpoint, but it can be said, without fear of contradiction, that some of the most important of them are insects. The predatory insects are found in a number of different families in several orders Some of the most effective in the forest are members of the Chrysopidæ, the Coccinellidæ, the Cleridæ, the Carabidæ, and several families of the Hemiptera Important examples of these families will be discussed in the following pages

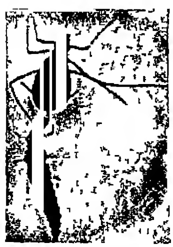


FIG. 143 —A lace-wing-fly larva feeding upon an aphid (*Cornell University*)

The Lace-Wing Flies.—Members of the family Chrysopidæ, of the order Neuroptera, are commonly called lace-wing flies (Fig 143) These insects are predaceous in both the larval and adult stages upon other small insects They are especially fond of aphids but they also eat scale insects, small caterpillars, and other small arthropods. It is only because larger insects are able to defend themselves against attack that they do not fall prey to lace-wing flies

These predators are useful as destroyers of aphids, especially when outbreaks of these insects occur late in the season Unfortunately, the lace-wing flies are not sufficiently numerous in the early part of the summer to be of much aid in reducing the number of other insects at that time of year As the season advances they become more and more numerous

The rapid increase in the number of the lace-wings, as the season advances, is made possible by the short life cycle of some

of the more common species Some of them pass through three or four generations during a season. Other species, however, do not multiply so rapidly. In fact some may only pass through one generation during a year These latter species are, of course, not important predators because they never become very numerous.

The adult lace-wing fly is a slender fragile-appearing insect, about ½ inch in length, with delicate, many-veined, membranous wings. The wings, when at rest, are folded against the body and meet over the insect's back in a form resembling a tent. The adults present anything but the appearance of predators The larvæ, on the other hand, look quite ferocious. They are elongate, somewhat flattened, and have a pair of long-curbed mandibles projecting forward from the mouth. These mandibles are hollow and it is through them that the insect sucks the blood of its prey

The habits of the lace-wing flies present a number of interesting features, the first of which is the habit of oviposition (Smith, 1922) When a female lace-wing is ready to lay an egg she touches her abdomen to the surface of the leaf or other object on which she is resting A drop of viscous fluid exudes from the end of her abdomen Then she pulls the drop of liquid out into a slender thread by raising her abdomen The thread quickly hardens in an erect position and on the top of it an egg is deposited In this way, the eggs are held almost ½ inch above the surface to which they are attached This method of placing the eggs on a stalk raises them out of reach of the cannibalistic lace-wing larvæ and other predaceous insects.

When the larvæ hatch from the eggs, they immediately start out in search of food Almost any insect that is small enough to be held is attacked, impaled upon the mandibles, and drained of its blood When food is abundant and temperature conditions are favorable, the larvæ grow rapidly They moult twice before they complete their growth.

When the third instar larvæ are full grown, they spin about themselves a light silken cocoon The cocoons may be located in bark crevices, on the lower side of a leaf, or in some other more or less secluded location Within the cocoon the larva passes through a prepupal stage before transforming to the pupal stage During the summer months, the pupal stage is completed in several weeks When pupation occurs in the autumn, on the

other hand, the pupal stage continues over winter and the adult does not emerge until early the following spring

The lace-wing flies, because of their good work in destroying aphids, are generally very beneficial insects. In some instances, however, their predaceous proclivities are not so much to be desired Occasionally, they may attack and kill the larvæ of coccinellids or other beneficial organisms. But in as much as this usually occurs only when aphids, scales, or other small insect pests are not numerous, it is not so serious as it might otherwise be.

Questions on Literature

1 What is the most common species of chrysopid in the eastern half of the United States?

2 How do the silk glands of the lace-wing flies differ from those of the true caterpillars?

3 In what way do some of the lace-wing flies protect themselves from observation during the larval stage?

4 With what other groups of predators do the lace-wing flies compete?

5 What are some close relatives of the lace-wing flies that are predaceous?

The Ladybird Beetles.—The Coccinellidæ are members of the order Coleoptera. They are for the most part predaceous. The adults of this family are called "ladybird beetles" (Fig 144) Like the lace-wing flies, these insects are predaceous upon small insects in both the adult and the larval stages Aphids or scale insects are their usual prey, but they will feed upon small caterpillars, mites, or almost any small organism that they may find In one instance, a comparatively large coccinellid, the fifteen-spotted ladybird beetle, *Anatis ocellata*, was partly responsible for checking an outbreak of the spruce budworm on jack pine

The life cycle of the ladybird beetles, as might be expected, varies somewhat with the species. Many of them have two or more generations even in northern latitudes while in the South a still greater number may be completed The insects pass the winter in the adult stage, hidden away in some protected location Many of them may creep into buildings for the purpose of hibernating. When spring arrives, the beetles leave their winter quarters and seek out suitable places for oviposition The eggs are laid in a variety of ways depending upon the species One of the California ladybirds, *Rhizobius ventralis*, deposits its eggs beneath the scale of the black-scale insects The larvæ that

hatch from these eggs feed upon the eggs of the scale (Quayle, 1911)

Some of our more common native species deposit their eggs in groups on the surface of the foliage upon which their prey feeds. The eggs are usually yellow in color and resemble somewhat those of some of the chrysomelids, the leaf beetles The larvæ that

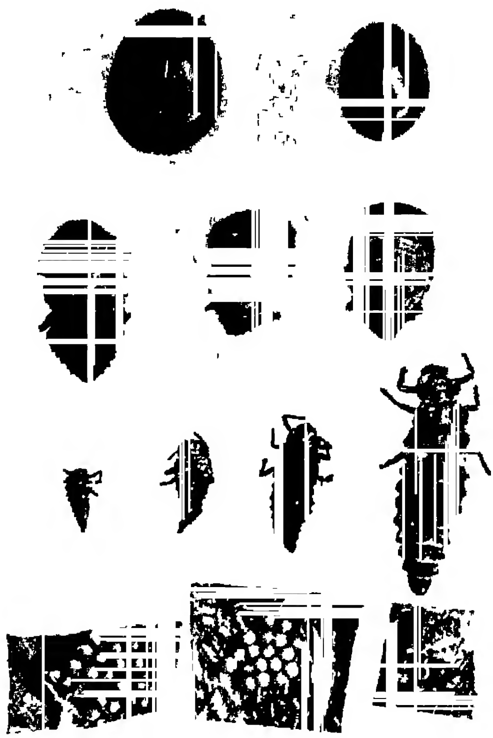


FIG 144 —The four stages in the development of a ladybird beetle from egg to adult (*Bureau of Entomology, U S. Dept Agr*)

hatch from these eggs are campodeaform and active Immediately after hatching, they begin to search for food. These larvæ are strange-looking creatures Many of them are mottled with contrasting colors and are covered with branched spines Their mandibles are long and sharp so that they are well equipped to capture small insects.

After the larvæ complete their growth they transform, usually on the tree, to the pupal stage These pupa are naked and are

often found in very conspicuous places Apparently most of these insects make no effort to seek a secluded place for pupation The beetles that emerge from the cocoons during the summer lay eggs immediately for another generation, whereas those that emerge in the autumn seek out a suitable place for hibernation and there spend the winter.

Questions on Literature

1 What ladybird beetles are especially valuable predators of the San José scale?

2 Into what part of the United States have a number of ladybird beetles been introduced?

3. How many eggs will a ladybird beetle usually lay?

4 Are all ladybird beetles predaceous?

5 At what season are these beetles most effective in controlling aphids?

The Checkered Beetles.—The family of beetles known as the Cleridæ is made up of species that are predaceous, for the most part, upon insects that tunnel into the bark, wood, or tips of trees The most common species in eastern United States is called the "American bark-beetle destroyer," *Thanasimus dubius* This species feeds almost exclusively upon various species of bark beetles.

The bark-beetle destroyer is large for a clerid. It measures nearly ½ inch in length. It is very brightly colored The ground color is red and on this background are markings of black and silver in transverse bands across the elytra. This type of marking is characteristic of the group and is the basis for the common name of the family, the checkered beetles These insects are predaceous in both adult and larval stages The adult preys upon adult bark beetles, whereas the larvæ feed upon the immature stages.

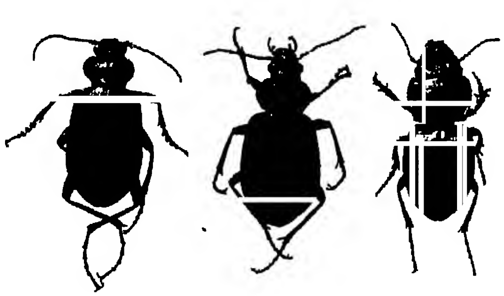
The eggs are deposited in the tunnels of bark beetles The larvæ are more or less grub-like in form with poorly developed legs but with powerful mandibles. They are usually pinkish in color. The larvæ are not at all uncommon beneath the bark of trees infested by bark beetles They feed upon both eggs and larvæ When they are numerous they materially reduce the bark beetles in number When they complete their development the larvæ cut their way into the outer bark. There they hollow out cells for themselves in which they pass through the pupal stage

According to Hopkins (1899), this insect may pass the winter in ıny stage of development from larva to adult In the spring, he beetles emerge in time for the spring flight of the bark eetles They may run rapidly over the surface of trees and ogs looking for their prey, or they may hide beneath a bark scale vaiting to pounce out upon any unfortunate bark beetle that may ass by

Questions on Literature

1. What species of checkered beetles are especially important in the ontrol of certain western bark beetles?
2 Are the clerids subject to the attack of parasites? If so, what are they?
3 What clerid was introduced into America in the hope that it would ecome established and aid in the control of bark beetles?
4 Are clerids specific or general in their feeding habits?
5 What are some of the distinguishing characteristics of the checkered eetles?

The Calosoma Beetles.—The ground beetles, or carabids Fig 145), belonging to the genus Calosoma are among the nportant predators of lepidopterous larvæ and pupæ The abits of these beetles have been studied in great detail in conection with the gypsy moth investigations in New England Burgess and Collins, 1917). The beetles of this group are mong the largest of the ground beetles.



ɑ 145—Three typical carabid beetles The beetles of this family are predacous in both adult and larval stages (*University of Minnesota*)

In a general way, the life cycle of the calosoma beetles is very milar for all the species that have been studied The eggs are eposited in the ground at a depth of from 4 to 6 inches, either ngly or in groups of two or three After an incubation period from 3 to 15 days, the eggs hatch and the larvæ make their way oward to the ground surface, where they proceed to search for

food. They prefer lepidopterous larvæ, but they will eat other insects if forced to do so by hunger

At the end of the third instar the larvæ have completed their growth. Then they again penetrate into the soil where they form for themselves earthen cells in which to pupate After from 10 to 15 days in these cells the adult stage is attained.

Some species, as soon as they have transformed to the adult stage, emerge and feed during the latter part of the summer and autumn Later they again bury themselves in the ground for hibernation Others, like the fiery hunter, remain in the young adult stage within their pupal cells until the following spring So far as is known, all the calosoma beeltes are unusually long lived Burgess and Collins (1917) report that in the field they may undoubtedly live, unless they meet with some accident, for at least 3 years. They report that one adult has lived for more than 4 years. Those beetles that lay eggs freely during their early life do not live as long as others that do not reproduce so freely.

Both the adults and larvæ feed upon lepidopterous caterpillars The species eaten will, of course, vary with the season and will depend upon the species available when feeding is going on In New England the gypsy moth is a favorite prey

The adult beetles will climb the trees in search of food, but the larvæ of most species feed almost exclusively upon the ground One outstanding exception to this is the fiery hunter, mentioned previously This insect climbs trees in both the adult and larval stages and is, therefore, a much more efficient factor of environmental resistance than any of our native species of the genus

Questions on Literature

1 When was the fiery hunter first introduced into America?

2. What important native forest pest has been controlled, in part at least, by a native calosoma beetle?

3. What factors of environmental resistance limit the effectiveness of calosoma beetles?

4. What are some of the natural enemies of these beetles?

5 Is there any likelihood that the fiery hunter may ultimately be reared in sufficient numbers, and at a sufficiently low cost, to make it a practical means of controlling lepidopterous insects in forests?

The Predaceous Bugs.—The order Hemiptera, in addition to the numerous species that suck the sap of trees, includes a great many predaceous species These predaceous forms are found in a

number of different families All the members of the family Reduviidæ, or assassin bugs, are predaceous and most of them are predaceous upon insects One of the well-known members of this family is the wheelbug, *Arilus cristatus* This insect is common throughout the eastern and central United States south of the latitude of New York City (Fig 146)

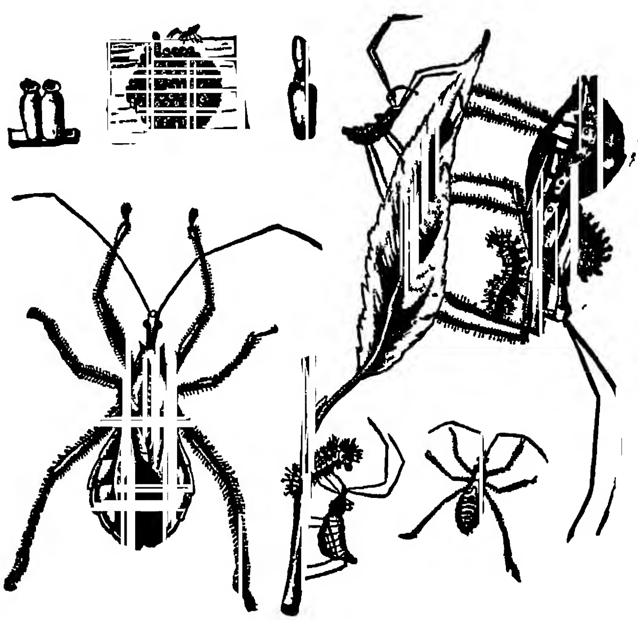


FIG 146—The various stages of the wheelbug, *Arilus cristatus* (*Comstock, "An Introduction to Entomology"*)

These wheelbugs lay their eggs upon plants or other objects in groups of 50 or even more The young nymphs that hatch from these eggs are bright red in color with rather long legs and long four-jointed antennæ They run about over plants seeking insect food In the early stages they feed for the most part upon aphids and other small insects As they increase in size they feed on larger insects When they are full grown they are ¾ inch in length and are able to attack and kill insects of considerable size

Another family of the Hemiptera that contains predaceous species is the family Pentotomidæ Some species of this family feed upon the juices of plants but many suck the blood of other

insects during at least a part of their lives. These predaceous species are often called soldier-bugs

One of these soldier-bugs is *Podisus placidus* (Fig 147). When in the adult stage, this predator is nearly ½ inch in length and in color, yellow mottled with brown It is predaceous upon many different species of caterpillars. Felt (1906) records the following species as being fed upon by this insect: the tent caterpillars, the pine sawfly, the senatorial oak caterpillar, the currant worm, the spiny elm caterpillar, the fall webworm, the white-marked tussock-moth, and the gypsy moth

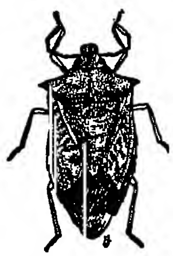


FIG 147.—The spined soldier-bug, *Podisus maculiventris* This species feeds upon a great variety of other insect species. (*Felt, Manual of Tree and Shrub Insects*)

The winter is passed by *Podisus placidus* in the adult stage. The overwintering adults appear in the early spring and after feeding for a week or two lay their eggs in groups on the under side of leaves or in other convenient places. When the young nymphs emerge, they are red and black in color Unlike the adults and older nymphs, the young nymphs are not predaceous Instead, they are phytophagous and feed upon the plant juices that they suck from the leaves of trees or shrubs Not until they have lived on a vegetable diet for a period of about 2 weeks do they adopt the predaceous habit Then they more than compensate for the insignificant amount of injury that has resulted from their feeding on the leaves by destroying numerous destructive insects. This soldier-bug has two generations in the North In the South it may have still more Several other families of the Heteroptera are predaceous upon insects, but none of them are as valuable predators of forest insects as the two discussed above.

Questions on Literature

1 What common name is frequently applied to the family Pentatomidæ? Why?

2 What similarities exist in the egg-laying habits of the predaceous Hemiptera?

3 Are there hemipterous insects that are predaceous upon animals other than insects? If so, what are some of them?

4 Are the soldier-bugs eaten to any great extent by birds?

5 What factors of environmental resistance prevent the predaceous Hemiptera from becoming so abundant that they exterminate the species on which they prey?

OTHER PREDATORS

In addition to the insect predators discussed in the preceding section, there are a number of other groups of insectivorous predators that should at least be touched upon briefly Among these are some other arthropods

Arthropods Other than Insects.—Among the organisms that prey upon insects the spiders and the mites should not be overlooked. It is a matter of common knowledge that spiders are highly insectivorous. They not only catch flies, and certain other more or less innocuous insects, but they also feed upon small larvæ of various kinds. The spiders that spin webs frequently capture larvæ that drop on threads and are blown about by the wind. Those spiders that actively hunt their prey are probably even more effective in the capture of larvæ.

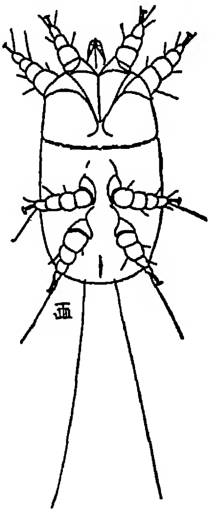


FIG 148 —The predaceous mite, *Hemisarcoptes malus*, one of the important enemies of the oyster-shell scale. (*Entomological Branch, Can Dept Agr*)

Strange as it may seem, however, no one has published the results of any quantitative study concerning the effectiveness of these animals It must be admitted, however, that spiders must exert a tremendously important influence upon the insect life in the forest The study of the effects of spiders upon forest insects offers a fertile field for future investigators

Likewise, when the literature is examined for facts concerning the predaceous mites, a decided shortage of information is found. One of the few that has been studied is the egg-destroying mite, *Hemisarcoptes malus* (Fig 148), which exercises an important controlling influence upon the oyster-shell scale (Tothill, 1918). In some localities this mite is the most effective single biotic factor of environmental resistance Doubtless, many other predaceous mites play an equally important role, but, unfortunately, comparatively little is known about them.

Insectivorous Vertebrates.—Another group of organisms that has already been mentioned as being insectivorous is the Vertebrata Some workers believe that this group contains some of the most effective insectivorous animals. Whether or not they are the most effective can only be a matter of conjecture until

available accurate quantitative data are secured on which to base a conclusion, but there can be no doubt that these organisms play an important part in reducing and holding down insect numbers.

General observation is sufficient to indicate that skunks, shrews, mice, and other mammals destroy great quantities of insects on or in the ground. It has been shown that mice and shrews are, at least in certain years and in certain localities, many times more effective in reducing the abundance of the larch sawfly during the cocoon stage than all the parasites combined (Graham, 1928).

But of all the vertebrates, the birds are probably the most important insect eaters. McAtee (1926) mentions numerous instances in which birds have brought insects under control. He cites the case of the snow-white linden moth that once was an exceedingly injurious pest of shade trees With the introduction and establishment of the English sparrow in the cities and towns of this country, the linden moth has become a rare insect Instances are cited in which birds have destroyed from 15 to 89 5 per cent of all the fall webworm larvæ in certain localities (Tothill, 1922) In a study of the natural agencies that control the white-marked tussock-moth, Dustan (1923) reports that almost every egg mass above the snow line was either partially or wholly destroyed by birds This amounted to 90 per cent of the egg masses The cankerworms, the tent caterpillars, the gypsy moth, in fact practically every kind of leaf-eating insect is fed upon by many species of birds.

Even the birds which are usually considered as being phytophagous are, without exception, insectivorous during the nestling stage. The fact that the nesting season of most birds coincides with the season of greatest insect abundance leads to a great abundance in number of insect-eating birds during that season Undoubtedly, the ability of many species of birds to change from insect to plant food, and *vice versa,* makes it possible for more birds to live in a locality, than if they all fed throughout the season on one type of food When insect food is abundant, the birds concentrate their attention upon that Later, when insects become scarce, fruit and seed are plentiful and provide food for birds In this way, the bird population is able to maintain itself, throughout the season, in sufficient numbers to make them effective agencies for controlling insects

Practically every species of insect has its bird enemies in almost every stage The eggs are eaten by small birds, nuthatches,

chickadees, the brown creeper, warblers, and kinglets, for example The larvæ are fed upon by almost every species of bird (Fig. 149). The pupæ likewise are searched out and eaten, even though they may be enclosed in strong cocoons

Even the boring insects are not without their bird enemies. The woodpeckers are most valuable in destroying these insects, as they bore for food beneath the bark or even into the wood When the adults of the borers fly from their old tunnels to a new host, they are subject to the attack of a long list of birds Fly catchers, the crow, jays, the bluebird, swallows, night hawk in fact, a long list of 100 or more species, feed upon adult borer

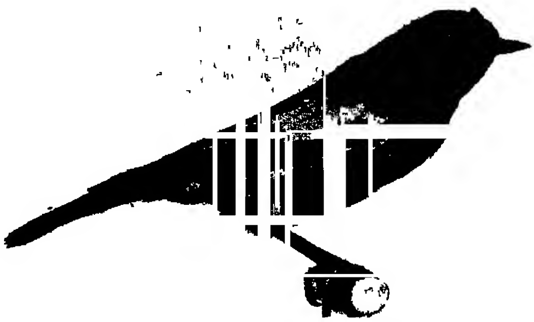


FIG 149 —The blackburnian warbler A bird that has proved itself to be a very effective check upon the spruce budworm (*University of Minnesota*)

One of the reasons that birds are sometimes especially effective in checking insect outbreaks is because of their great powers of mobility This permits them to concentrate in those places where insects are most numerous. Because of this ability many incipient insect outbreaks are checked by these valuable predators

Questions on Literature

1 What species of birds would you expect to be most valuable in checking defoliators in an oak and maple forest?

2 What are some of the mites other than *Hemisarscoptes malus* that are predaceous upon insects?

3 Of what value are birds in checking the multiplication rate of the fall webworm?

4 What groups of insects are most susceptible to the attack of vertebrates other than birds?

5 What species of birds are known to feed upon the wood-boring insects? Upon bark beetles? Upon white grubs?

BIBLIOGRAPHY

Chapter I—Introduction

BANKS, N , 1906 "Bibliography of the More Important Contributions to Economic Entomology" vols 6–8, 1888 to 1905

———, 1916. "Index to the Literature of American Economic Entomology" vol 1, 1905–1914

COLCORD, M , 1921, 1926 "Index to the Literature of Economic Entomology" vols 2 and 3, 1915–1919, 1920–1924

COMSTOCK, J. H , 1925 "An Introduction to Entomology"

ESSIG, E O , 1926. "Insects of Western North America"

FELT, E P , 1924. "Manual of Tree and Shrubs Insects"

GRAHAM, S A , and A G RUGGLES, 1923 The obligation that economic entomology owes to forestry, *Jour Econ Ent*, **16**. 51–61

HAGEN, H A , HORN, W , and SCHENKLING, S , 1928–9 "Index Litteraturæ Entomologicæ" 4 vols to 1863

HENSHAW, S , 1888. "Bibliography of the More Important Contributions to American Economic Entomology" vols 1–5

HOUSER, J. S , 1918 Destructive insects affecting Ohio shade and forest trees, *Ohio Agr. Exp Sta*, *Bull* **332**. 161–487

KOTINSKY, J , 1921 Insects injurious to deciduous shade trees and their control, *U. S Dept Agr*, *Farmers' Bull* 1169

PACKARD, A S , 1890 Insects injurious to forest and shade trees, *Ent Comm*, *Fifth Rept*

PEIRSON, H B , 1927 Manual of forest insects, *Maine Forest Service, Bull* 5

SNYDER, T E , 1927 Defects in timber caused by insects, *U S Dept Agr., Bull* 1490

SWAINE, J M , 1918 Canadian bark-beetles, *Can Dept Agr Ent Branch, Tech Bull* 14

SWAINE, J M , and C B HUTCHINGS, 1926 The more important shade-tree insects of Eastern Canada, *Can Dept Agr*, *n s*, *Bull* 63

WARDLE, R. A. and P. BUCKLE, 1923. "The Principles of Insect Control"

Chapter II—Historical Review

NÜSSLIN O , and RHUMBLER, L., 1922 "Forstinsektenkunde" pp 1–9

Chapter III—Biotic Potential

CHAPMAN, R N , 1925 "Animal Ecology with Special Reference to Insects," pp 143–149

FOLSOM, J W , 1922 "Entomology with Special Reference to Its Ecological Aspects," pp 123–136,

Graham, S. A., 1926 Biology and control of the white-pine weevil, *Cornell Agr Exp Sta*, *Bull* 449

LeFroy, H M, 1909 "Indian Insect Life," 624

Thompson, W R., 1922. Etude de quelques cas simples de parasitisme cyclique ches les insects entomophages, *Comp. rend Acad Sci Paris*, **174**: 1647–1649.

———, 1922, Theorie de l'action des parasites entomaphages, *Comp. rend. Acad. Sci. Paris*, **175**: 65–68.

Chapter IV—Environmental Resistance

Baumberger, J P, 1919 A nutritional study of insects with special reference to micro-organisms and their substrata, *Jour Exp. Zool*, **28**: 1–81

Blackman, M. W, 1918 The apple tent-caterpillar, *Jour Econ Ent*, **9**: 432

Carpenter, F W, 1909 Some reactions of Drosophila, *Jour Comp Neurol* and *Psych*, **18**: 483–491

Chapman, R N, 1915 Observations on the life history of *Agrilus bilineatus*, *Jour Agr Res*, **3**: 283–294

———, 1925. "Animal Ecology with Special Reference to Insects," pp 149–158.

Craighead, F C, 1921 Hopkins' host-selection principle as related to certain cerambycid beetles, *Jour. Agr Res*, **22**: 189–220

———, 1925 Relation between mortality of trees attacked by spruce budworm and previous growth, *Jour Agr Res*, **30** 541–555

Cook, W C, 1927 Some effects of alternating temperature on growth and metabolism of cutworm larvæ, *Jour Econ Ent*, **20**. 769–782

Graham, S A, 1920 Factors influencing the subcortical temperature of logs, *Minn State Ent Rept*, **18**: 26–42

———, 1922 Effect of physical factors in the ecology of certain insects in logs, *Minn State Ent Rept*, **19**. 22–40

———, 1924 Temperature as a limiting factor in the life of subcortical insects, *Jour Econ Ent*, **17**: 377–383

———, 1926 Biology and control of the white-pine weevil, *Cornell Agr Exp Sta*, *Bull* 449.

Hopkins, A D, 1920 The bioclimatic law, *Jour Wash Acad Sci*, **10**: 34–40

———, 1921 Bioclimatic zones determined by meteorological data, *U S Dept Agr Weather Rev*, **49** 229–330

———, 1921 Bioclimatic zones of continents with proposed designations and classification, *Jour Wash Acad Sci*, **11**: 227–229

Howard, L O, 1926 The parasite element of natural control of injurious insects and its control by man, *Jour Econ Ent*, **19** 271–282

Krogh, A, 1914 The quantitative relation between temperature and standard metabolism in animals, *Intern Zeitschr Physik-Chem Biol*, **1** 491–508

———, 1914 On the influence of temperature on the rate of embryonic development, *Zeitschr Allge Physiol*, **16**: 163–167

———, 1914 On the rate of growth and CO_2 production of chrysalides of *Tenebrio molitor* at different temperatures, *Zeitschr Allge. Physiol*, **16**. 178–190
MERRIAM, C H, 1898 Life zones and crop zones in the United States, *U S Dept Agr Biol Survey, Bull* 10
PAYNE, N M, 1926 Freezing and survival of insects at low temperatures, *Quart Rev Biol*, **1** 270–282
———, 1926 The effect of environmental temperatures upon insect freezing points, *Ecology*, **7**: 99–106
PEAIRS, L M, 1927 Some phases of the relation of temperature to the development of insects, *W Va Agr Exp Sta*, *Bull* 208
ROBINSON, WM, 1927 Water-binding capacity of colloids a definite factor in winter hardiness of insects *Jour Econ Ent*, **20** 80–88
PIERCE, W D, 1916 A new interpretation of the relationships of temperature and humidity to insect development, *Jour Agr Res*, **5** 1183–1191.
SANDERSON, E D, 1908 The relation of temperature to the hibernation of insects, *Jour Econ Ent*, **1**. 56–65
SANDERSON, E D, and L M PEAIRS, 1913 The relation of temperature to insect life, *N H Coll Agr Exp Sta*, *Tech Bull* 7
SNYDER, T E, 1926 Preventing damage by lyctus powder-post beetles, *U S Dept Agr Farmers, Bull* 1477 1–13
SUMMERS, J N, 1922 Effect of low temperature on the hatching of gypsy-moth eggs, *U. S. Dept. Agr., Bull.* 1080.

Chapter V—Insect Abundance

CHAPMAN, R N, 1925 "Animal Ecology with Special Reference to Insects," pp 143–158
FOLSOM, J W, 1922 "Entomology," Chaps VI, XI, and XII
GEROULD, J H, 1916 Mimicry in butterflies, *Amer Nat*, **50**: 184–192
POULTON, E B, 1890 "The Colours of Animals"
PUNNETT, R C., 1915 "Mimicry in Butterflies"

Chapter VI—Direct Control of Tree Insects

CRAIGHEAD, F C, 1920 Direct sunlight as a factor in forest insect control, *Proc Ent*, *Soc Wash*, **22** · 106–108
———, 1921 Temperatures fatal to larvæ of the red-headed ash-borer, *Jour Forestry*, **19**. 250–254
———, 1921 Protection of mesquite cordwood and posts from borers, *U S Dept Agr*, *Farmers' Bull* 1197
GRAHAM, S A, 1920 Factors influencing the subcortical temperatures of logs, *Minn State Ent*, *Rept*, **18**. 26–42
JONES, D W, 1926 Some notes on the technic of handling parasites, *Jour Econ Ent*, **19**. 311–316
SMITH, H S, 1921 Biological control of the black scale, *Jour Econ Ent*, **14**. 348–350
———, 1925 The commercial development of biological control in California, *Jour Econ Ent*, **18**. 147–152

———, 1926. The present status of biological control work in California, *Jour Econ Ent*, **19**: 294–302
Turner, W. B, 1918, Female Lepodoptera at light traps, *Jour Agr Res*, **14**: 135–149
———, 1920. Lepodoptera at light traps, *Jour Agr Res*, **18**. 475–481.
Wardle, R A, and P Buckle, 1923 "The Principles of Insect Control."

Chapter VII—Direct Control by Chemical Methods

Craighead, F. C, 1915 A new mixture for controlling wood-boring insects, *Jour Econ Ent*, **7**: 513
Fracker, S. B, and A Granovsky, 1928 Airplane dusting to control the hemlock spanworm, *Jour Forestry*, **26**: 12–33
Kotinsky, J, 1921 Insects injurious to deciduous shade trees and their control, *U. S Dept. Agr, Farmers' Bull* 1169
Moore, Wm., and S. A Graham, 1918 Physical properties governing the efficacy of contact insecticides, *Jour Agr Res*, **13** 523–538
Moore, Wm, 1925 Electric charges of arsenical particles, *Jour Econ Ent*, **18**. 282–286
Worthley, L H, 1917 Solid-stream spraying against the gypsy moth, *U S Dept Agr, Bull* 480

Chapter VIII—Indirect Control of Tree Insects

Burke, H E, 1921 Notes on the carpenter worm and a new method of control, *Jour Econ. Ent*, **14** · 369–372
Collins, C W, 1920 Gypsy-moth tree-banding material, *U S Dept Agr, Bull* 899
Craighead, F C., 1922. Experiments with spray solutions for preventing insect injury to green logs, *U S Dept Agr, Bull* 1079
Graham, S. A, 1916 Notes on the control of the white-pine weevil, *Jour Econ Ent*, **9** · 549–551
———, 1922 Some entomological aspects of the slash-disposal problem, *Jour. Forestry*, **20** 437–447
———, 1925. The felled tree trunk as an ecological unit, *Ecology*, **6** 397–411
Keen, F P., F C Craighead, *et al* 1927 The relation of insects to slash disposal, *U S. Dept Agr, Circ* 411
Miller, J M, 1926 The western pine beetle control problem, *Jour Forestry*, **24**: 897–910
Peirson, H B, 1921 The life history and control of the Pales weevil, *Harvard Forest Bull* 3
Preston, J. F, 1925 Control of bark beetles on the national forests, *Jour Forestry*, **23**: 49–61
Pettit, R H, 1923 A successful repellent for the flat-headed borer, *Mich State Bd of Agr, Rept* **62** · 219–235
Snyder, T. E, 1921, White ant-proof wood for the tropics, *Jour Econ. Ent*, **14** · 496-501
———, 1924 Tests of methods of protecting woods against termites, *U S Dept Agr Bull* 1231

———, 1926 Preventing damage by lyctus powder-post beetles, *U S Dept Agr*, *Farmers' Bull* 1477 1–13

Chapter IX—Other Indirect Control Methods

BURGESS, A F, 1926 The present status of the control of the gypsy moth and brown-tail moth by means of parasites, *Jour Econ Ent*, **19**: 289–294

BURGESS, A F, and C W COLLINS, 1915 The calosoma beetle, *U S. Dept Agr*, *Bull* 251

CHAPMAN, R N, 1915 Observations on the life history of *Agrilus bilineatus*, *Jour. Agr Res*, **3**. 283–294

CLEMENT, G E, and W MUNRO, 1917 Control of the gypsy moth by forest management, *U S Dept Agr*, *Bull* 484

CRAIGHEAD, F C 1919 Protection from the locust borer, *U S Dept Agr*, *Bull* 787

———, 1925 Relation between the mortality of trees attacked by spruce budworm and previous growth, *Jour Agr*, *Res*, **30**. 541–555.

GRAHAM, S A, 1926 Biology and control of the white-pine weevil *Cornell Agr Exp Sta*, *Bull* 449

———, 1928 The influence of small mammals and other factors upon larch sawfly survivial, *Jour Econ Ent*, **21**· 301–310

———, and L G BAUMHOFER, 1927 The pine tipmoth in Nebraska National Forest, *Jour Agr Res*, **35**. 323–333

———, and L G BAUMHOFER 1928 Susceptibility of pines to tipmoth injury (*in manuscript*)

HARTLEY, CARL, 1927 Forest genetics with particular reference to disease resistance, *Jour Forestry*, **25**· 667–686

HOWARD, L O, 1926 The parasite element of natural control of injurious insects, *Jour Econ Ent*, **19**· 271–282

———, 1922 A side line on the importation of insect parasites of injurious insects, *Proc Nat Acad Sci*, June, 1922

MOSHER, F. H, 1915 Food plants of the Gypsy moth, *U S Dept Agr*, *Bull* 250.

PEMBERTON, C E., and H. F. WILLARD, 1918 Interrelations of fruit-fly parasites in Hawaii, *Jour Agr Res*, **12**. 285–296

ROESER, JACOB Jr, 1926. The importance of seed source and the possibilities of forest-tree breeding, *Jour Forestry*, **24** 38–51

THOMPSON, W R, 1923. A criticism of the "sequence" theory of parasitic control, *Ann Ent*, *Soc Am*, **16**: 115–128

WILLIAMS, C B, 1918 The food of the mongoose in Trinidad, *Trinidad and Tobago Dept. Agr*, *Bull* **17**. 167–186

WILLARD, H F, and T L BISSELL, 1926 Work and parasitism of the Mediterranean fruit fly in Hawaii, *Jour Agr*, *Res*, **33** 9–15

Chapter X—Leaf-eating Insects

Birch-leaf Skeletonizer, *Bucculatrix canadensisella* Chamb

FRIEND, R. B, 1927 *Conn Agr Exp Sta*, *Bull* 288

LINTNER, J A, 1893 Insects of New York, *8th Rept*, 133–140, 1891

Black-walnut Caterpillar, *Datana integerrima* Grote and Rob
FELT, E P, 1905 New York State Museum, *Memoir* **8**. 303–305
Brown-tail Moth, *Euproctis chrysorrhœa* L
BRITTON, W. E., 1914 *Conn. Agr. Exp. Sta*, *Bull* 182
———, *et al*, 1919 *Conn. State Ent Rept*, *Bull.* **211** · 272–290
BURGESS, A. F., 1917 *U. S Dept. Agr*, *Farmers' Bull* 845
California oak worm, *Phryganidia californica* Pack
BURKE, H E, and F. B HERBERT, 1920 *U S Dept Agr*, *Farmers' Bull* 1076.
Cankerworms
PORTER, B. A. and C. H. ALDEN 1924 *U S Dept Agr*, *Farmers' Bull* 1238.
Catalpa sphinx, *Ceratomia catalpæ* Bvd
HOUSER, J. S, 1908 *Ohio Agr Exp Sta*, *Bull* **332**: 238–241
HOWARD, L. O., and F. H CHITTENDEN, 1907 *Dept Agr Bur Ent.*, *Circ* 96.
Elm leaf-beetle, *Galerucella luteola* Mull
HERRICK, G W, 1911 *Cornell Agr Exp Sta*, *Circ* 8
Elm-leaf sawfly, *Kaliosphinga ulmi* Sund
CHRYSTAL, R N., 1919. *Agr Gazette Can*, **6** 725–728
SLINGERLAND, M. V, 1905 *Cornell Agr Exp Sta*, *Bull* **233**: 51–57
Evergreen bagworm, *Thyridopteryx ephimeræformis*, Haw
HOWARD, L O, and F H CHITTENDEN, 1916 *U S Dept Agr Bur Ent*, *Farmers' Bull* 701
Fall webworm, *Hyphantria textor* Harris
TOTHILL, J D, 1922 *Can Dept Agr*, *Tech Bull* **3** 3–107
Forest tent-caterpillar, *Malacosma disstria* Hubn ·
HOUSER, J S, 1918 *Ohio Agr Exp Sta*, *Bull* **332**. 241–244
SLINGERLAND, M V, 1899 *Cornell Agr Exp Sta*, *Bull* **170**: 557–564
SWAINE, J M, 1913. *Can Dept Agr Ent*, *Branch*, *Circ* 1
Gypsy moth, *Porthetria dispar* L
BURGESS, A F, 1917 *U S Dept Agr Farmers' Bull* 845
COLLINS, C W, 1915 *U. S. Dept Agr*, *Bull* 273
FISKE, W F, 1913 *U S Dept Agr Bur Ent*, *Circ* 164
Green maple-worm, *Xylena antennata* Walker
FELT, E P, 1912 *New York State Museum*, *Bull.* **155**: 48–52
Green striped-maple worm, *Anisota rubicunda*, Fabr
HOWARD, L. O, and F H CHITTENDEN, 1909 *U. S Dept Agr. Bur. Ent*, *Circ* 110
Hemlock looper, *Ellopia fiscellaria* Guenee
DIBBLE, C B, 1926 *Mich Quart Bull*, **8** · 145–148
FRACKER, S B, and A GRANOVSKI, 1927 *Jour Econ Ent*, **20**: 287–295
Larch case-bearer, *Coleophora laricella* Hubn
BRITTON, W E, 1924 *Conn Agr Exp Sta*, *Bull* **256** · 288–291
HERRICK, G W, 1912 *Jour Econ Ent*, **5** 172
Larch sawfly, *Lygaeonematus erichsonii* Hart
HEWITT, C G, 1912 *Can Dept Agr Div Ent*, *Bull* 10
Lodgepole pine needle-miner, *Recurvaria milleri* Busck
PATTERSON, J E, 1921 *Jour Agr Res*, **21** 127–142

Maple case-bearer, *Paraclemensia acerifoliella* Fitch
HERRICK, G W, 1923 *Cornell Agr Exp Sta*, *Bull* 417
Pandora moth, *Coloradia pandora* Blake
ELDREDGE, D F, 1923 *Am For*, **254**: 330–332
PATTERSON, J E, 1923 *Timberman*, p 39, June, 1923
Pine butterfly, *Neophasia menapia* Felder
EVENDEN, J C., 1924 *Timberman*, p 54, May, 1924
———, 1926 *Jour Agr Res*, **33**· 339–344
JONES, U and H. SCHMITZ, 1923 *Timberman*, pp 156–157, Jan 1923
Pine sawflies
GRAHAM, S A, 1925 *Jour Econ Ent*, **18**· 337–345
MIDDLETON, WM, 1921. *Jour Agr Res*, **20**. 741–760
MIDDLETON, WM, 1922. *U S Dept Agr*, *Farmers' Bull* 1259
———, 1923 *U S Dept Agr*, *Farmers' Bull* 1182
Poplar leaf-beetle, *Lina scripta* Fab
FELT, E P, 1906 *New York State Museum, Mem* **8** 317–321
Satin moth, *Stilpnotia salicis* Linn
BURGESS, A F, 1927 *U. S Dept Agr*, *Bull* 1469
GLENDENNING, R, 1924 *Can Dept Agr*, *n s*, *Pamphlet* **50.**
Snow-white linden moth, *Ennomos subsignarius* Hubn
FELT, E P, 1908. *New York State Museum, Bull* **124**· 23–28
HERRICK, G W, 1910 *Cornell Agr Exp Sta*, *Bull* 286
Spiny elm-caterpillar, *Aglais (Euvanessa) antiopa* Linn
FELT, E P, 1906 *New York State Museum, Mem* **8**. 158–162
Spruce budworm, *Archips fumiferana* Clem
CRAIGHEAD, F C, 1924 *Can Dept Agr*, *Bull* 37
GRAHAM, S A, 1923 *Univ Minn Special Bull* 68
White-marked tussock-moth, *Hemerocampa leucostigma* Abb and Sm
FELT, E P, 1912 *New York State Museum, Bull* **156**. 14–17
HOUSER, J S, 1918 *Ohio Agr Exp Sta*, *Bull* **332** 207–213
RUGGLES, A G, 1917 *Minn State Ent*, *Circ* 46
SWAINE, J M, 1918 *Can Dept Agr Ent*, *Branch, Circ* **11**
Yellow-striped oak-caterpillar, *Anisota senatoria* Abb and Sm
HAUSER, J S, 1918 *Ohio Agr Exp Sta*, *Bull* **332** 249–251

Chapters XI, XII, and XIII—Meristem Insects

Aspen borer, *Saperda calcarata* Say
FELT, E P, and L H JOUTEL, 1904 *New York State Museum, Bull* **74**· 39–44
HOFER, GEORGE 1920 *U S Dept Agr*, *Farmers' Bull* **1154**· 3–11
Balsam-fir bark-beetle, *Pityokteines sparsus* Lec
SWAINE, J M, 1919 *Quebec Soc Protection Plants, Ann Rept* **11** 46–48
Basswood borer, *Saperda vestita* Say
FELT, E P, and L. H JOUTEL, 1904 *New York State Museum, Bull* **74** 54–58
Black hills beetle, *Dendroctonus ponderosæ* Hopk
HOPKINS, A D, 1905 *U S Dept Agr Bur Ent*, *Bull* 56
Black turpentine beetle, *Dendroctonus terebrans* Oliv
HOPKINS, A D, 1909 *U S Dept Agr Bur Ent*, *Bull* 83, pt 1.

Bronze birch-borer, *Agrilus anxius* Gory

BLACKMAN, M W, and W O ELLIS, 1916 *New York State Coll. Forestry, Bull* 26 46–49

BRITTON, W E, 1922. *Conn Agr Exp Sta, Bull* 247 359–361.

PEIRSON, H B, 1927. *Jour Forestry*, **25**: 68–72

SLINGERLAND, M V, 1906 *Cornell Agr Exp Sta, Bull* 234 65–78

Carpenter moth, *Prionoxystus robiniæ* Peck

BURKE, H E, 1921. *Jour Econ Ent*, **14**: 369–372

FELT, E P, 1905 *New York State Museum, Mem* **8** · 79–84

PACKARD, A S, 1890 *Ent Comm, Rept* 5 53–58

Cottonwood borer, *Plectrodera scalator* Fabr

MILLIKEN, F B, 1916 *U. S. Dept Agr, Bull* 424

Destructive spruce beetle, *Dendroctonus piceaperda* Hopk

HOPKINS, A D, 1909 *U. S. Dept Agr Bur Ent, Bull* 83, pt 1.

SWAINE, J M, 1924, *Can. Dept. Agr., n. s. Pamphlet* 48

Dipterous cambium miners

BURKE, H E, 1905 *U S Dept. Agr. Bur Ent, Circ* 61 1–10

GREEN, C T, 1914 *Jour Agr Res*, **1**: 471–474

Douglas-fir pitch-moth, *Synthadon novaroensis*, Edw

BRUNNER, JOSEF., 1915 *U S Dept Agr, Bull* 255

Elm snout-beetle, *Magdalis barbita* Say and *M armicollis* Say

FELT, E P, 1905 *New York State Museum, Mem* 8 73–75.

HUBBARD, H G, 1874 *Psyche*, **1**. 5–6

European pine-shoot moth, *Evetria buoliana* Shiff.

BUSCK, AUGUST, 1915 *U. S Dept Agr, Bull* 170 1–11

BRUNNER, JOSEPH, 1915 *U S Dept Agr Bull* 295 1–12

Flat-headed borer, *Chrysobothris femorata* Fab

BROOKS, F E, 1919 *U. S Dept Agr Farmers' Bull* 1065 3–12.

BURKE, H E, 1919 *Jour. Econ Ent*, **12** · 326–330

Hickory bark-beetle, *Eccoptogaster quadrispinosus* Say·

BLACKMAN, M W, 1924 *Jour Econ Ent*, **17**. 460–470

HOPKINS, A D, 1912 *U S Dept Agr Bur. Ent, Circ* 144

Large pine-sawyer, *Monochamus confusor* Kirby·

SWAINE, J M, 1917 *Ont Ent, Soc, Rept.* 471: 96–97

Leopard moth, *Zeuzera pyrina* Linn

BRITTON, W E and G A. CROMIE, 1911. *Conn Agr Exp Sta, Bull.* 169 3–24

HOWARD, L O and F H CHITTENDEN, 1916 *U S Dept Agr Farmers' Bull* 708

Locust borer, *Cyllene robiniæ* Forst :

CRAIGHEAD, F C, 1919 *U S Dept Agr, Bull* 787 1–12

GARMAN, H, 1915 *Ky State Forester, Bien Rept* 2: 3–21

Mountain pine-beetle, *Dendroctonus monticolæ* Hopk

CRAIGHEAD, F C, 1925 *Jour Forestry*, **23** · 340–354

HOPKINS, A D, 1909 *U S Dept Agr Bur Ent, Bull* 83, pt 1.

HOPPING, RALPH, 1921 *Can Dept Agr Ent, Branch, Circ* 15

Oak twig-girdler, *Agrilus angelicus* Horn and *A arcuatus targuatus*

BURKE, H E, 1920 *Jour Econ Ent*, **13** 379–384

RUGGLES, A G, 1919 *Minn State Ent, Rept* 17 15–20

Pales weevil, *Hylobius pales* Herbst
Peirson, H B , 1921 *Harvard Forest Bull* 3 1–33
Pine bark-beetle, *Ips pini* Say
Clemens, W A , 1916 *Cornell Agr Exp Sta* , *Bull* 383 287–298
Pine pitch-mass borer, *Parharmonia pini* Kellicott
Felt, E P , 1905 *New York State Museum, Mem* 8 341–342
Pine pityogenes, *Pityogenes hopkinsi* Sw
Blackman, M W and J M Swaine, 1915 *N Y State Coll Forestry, Tech Pub* 2.
Pine tipmoth, *Rhyacionia frustrana* Scudder
Graham, S A and L. G Baumhofer, 1927. *Jour Agr Res* , **35**· 323–333
Red turpentine beetle, *Dendroctonus valens* Lec
Hopkins, A D , 1909 *U S Dept Agr Bur Ent* , *Bull* 83, pt 1
Sequoia pitch-moth, *Vespamima sequoia*
Brunner, Joseph, 1914 *U S Dept Agr* , *Bull* 111
Small pine-sawyer, *Monochamus scutellatus* Say
Tothill, J D , 1923 *New Brunswick Land Dept* , *Ann Rept* 63 86–87
Southern pine-beetle, *Dendroctonus frontalis* Zimm
Craighead, F. C , 1925 *Jour Econ. Ent* , **18**· 577–586
Hopkins, A. D , 1920 *U S Dept Agr* , *Farmers' Bull* 1188
Sugar-maple borer, *Glycobius* (*Plagionotus*) *speciosus* Say
Britton, W E , 1922 *Conn Agr Exp Sta* , *Bull* 247 351–355
Blackman, M W and W. O Ellis, 1916 *New York State Coll Forestry,* **16**, 26 60–65.
Kotinsky, Jacob, 1921, *U. S Dept Agr* , *Farmers' Bull* 1167 53–55
Two-lined borer, *Agrilus bilineatus* Weber
Chapman, R N , 1915 *Jour Agr Res* , **3** 283–294
Western pine-beetle, *Dendroctonus brevicomis* Lec
Chamberlin, W J , 1920 *Ore Agr. Exp Sta* , *Bull* 172
White grubs, *Phyllophaga* (*Lachnosterna*)
Forbes, S A., 1907 *Univ. Ill Agr Exp. Sta* , *Bull* 116
White pine-weevil, *Pissodes strobi* Peck
Graham, S A , 1918 *Jour Forestry,* **15**. 192–202
——, 1926 *Cornell Agr Exp Sta* , *Bull* 449 3–32
Hopkins, A D , 1907. *U S Dept Agr Bur Ent* , *Circ* 90 1–8
Peirson, H B , 1922 *Harvard Forest Bull* 5 1–42
Willow Curculio, *Cryptorhynchus lapathi* Linn
Blackman, M. W., and W. O. Ellis, 1915 *New York State Coll Forestry, Bull.* 26: 67–71.
Matheson, Robert, 1915. *Jour. Econ Ent* , **8** 522–525
———, 1917. *Cornell Agr. Exp Sta* , *Bull* 388
Wireworms
Hyslop, J A , 1916. *U S Dept Agr* , *Farmers' Bull* 725
Lane, M C , 1925. *Jour Econ Ent* , **18**: 90–95
Zimmerman pine moth, *Pinipestis zimmermani* Grote
Felt, E P , 1915. *New York State Museum, Bull* 180 39–42

Chapter XIV—Wood Destroyers

Ambrosia beetles.
FELT, E P, 1905 *New York State Museum, Mem* 8· 289–293
HOPKINS, A D, 1905 *U S Dept Agr Bur. Ent, Circ* 82 1–4
HUBBARD, H G, 1897 *U S Dept Agr Div Ent, n s Bull* 7
Buprestid dry-wood borer, *Chrysophana placida* Lec
BURKE, H E, 1917. *Jour. Econ Ent*, **10**. 406–407
Carpenter ant *Camponotus pennsylvanicus* Degeer
COMSTOCK, J H, 1915 "Manual for the Study of Insects"
GRAHAM, S A, 1918 *Minn State Ent, Rept* 17 32–40
WHEELER, W M, 1910, "Ants Their Structure, Development, and Behavior"
Carpenter bee, *Xylosopa orpifix* Smith·
NININGER, H H, 1916 *Jour Ent., and Zoöl*, **8**· 157–166
Horntails
FELT, E P, 1905 *New York State Museum, Mem* 8 667–669
HARRINGTON, W H, 1883 *Ont Ent Soc, Rept* 14 40–42
RILEY, C V, 1888 *Insect Life*, **1**: 168–179
Marine borers
BARTSCH, PAUL, 1922. *Smith. Inst. U S Nat Mus, Bull* 122
CALMAN, W T, 1919 *Br Museum (Nat Hist), Econ Ser* 10
DOVE, W H, and R C MILLER, 1923 *Univ Cal Pub Zoöl*, **22**: 383–400.
MILLER, R C, and L C. BOYNTON, 1926 *Science, n s* **63** 524
SIGERFOOS, C. P, 1907. *U S Bur Fish, Bull* **27**: 191–231
SMITH, S C, 1907 *U. S Dept Agr Forest Serv, Circ* **128**: 3–15
Parandra borer, *Parandra brunnea* Fabr
BROOKS, F E, 1915 *U S Dept Agr, Bull* **262**. 1–7
SNYDER, T E, 1910. *U S Dept Agr, Bur Ent, Bull* **94** 1–11.
———, 1911 *U S Dept Agr Bur Ent, Circ* 134
Powder-post beetles
BLAKE, E G, 1925 "Enemies of Timber Dry Rot and the Death-watch Beetle"
SNYDER, T E, 1916, *Jour Agr Res*, **6** 273–276
———, 1926, *U S Dept Agr, Farmers' Bull* **1477**. 1–12
Western cedar-pole borer, *Trachykele blondeli* Mars
BURKE, H. E, 1928, *U S Dept Agr, Tech Bull* 48

Chapter XV—Sap-sucking Insects

Adelgids
CHRYSTAL, R. N, 1916 *Ont Ent Soc, Rept* 1916, 123–130
———, 1922 *England Forestry Comm, Bull* 4
HERRICK, G W, and T TANAKA, 1926 *Cornell Agr Exp Sta, Bull* 454
Aphids
JONES, T H, and C P GILLETTE, 1918 *Jour Agr Res*, **14**: 577–593
PATCH, E M, 1915 *Maine Agr Exp Sta, Bull* 241
———, 1920 *Ann Ent, Soc Am*, **13** 156–167
———, 1923 *Maine Agr. Exp Sta, Bull* 313

Lace bugs:
BARBER, H G, and H B WEISS, 1922 *N. J Dept Agr Bur Stat* and *Insp., Circ.* **54**: 3–21
DRAKE, C J, 1922. *New York State Coll Forestry Tech Pub* **16**: 111–116.
WADE, OTIS, 1917. *Okla Agr Exp Sta, Bull* 116
Plant bugs
BAILEY, H L, 1920 *Vt Com Agr*
FELT, E P, 1905 *New York State Museum, Mem* **8** 239–240
LINTNER, J A, 1895 Insects of N Y, *Rept* **10** 432–439
Periodical cicada, Tibicina septendecim
FELT, E P, 1905 *New York State Museum, Mem* **8**: 231–237
MARLATT, C L, 1907 *U. S. Dept Agr Bur Ent, Bull* **71**· 5–181
Scale insects
BLACKMAN, M W, and W O ELLIS, 1916 Cottony maple-scale, *New York State Coll Forestry, Bull* **16**: 26–107
COMSTOCK, J H, 1883 *Cornell Agr Exp Sta, Second Rept*
DOZIER, H L, 1925 Obscure scale, *Fla State Plant Bd, Quart Bull* **9**· 129–133
GILLETTE, C P, and G. S LANGFORD, 1925 *Colo. State Ent, Circ* 46
GRISWOLD, G H, 1925 Oyster-shell scale, *Cornell Agr Exp Sta*, Mem 93
HERBERT, F B 1920 Cyprus bark-scale, *U S Dept Agr Bull* 838
———, 1924 European elm-scale, *U S Dept Agr, Bull* 1223
HOUGH, W S, 1925 Comstock's mealybug, *Va Agr Exp Sta, Tech Bull* 29
QUAINTANCE, A L, and E R SASSCER, 1910 Oyster-shell scale, *U S Dept Agr Bur Ent, Circ* 121

Chapter XVI—Parasites

ALLEN, H W, 1925 The biology of the red-tailed tachinid fly, *Miss Agr Exp Sta, Bull* 12
BALDUFF, W V, 1926 The bionomics of *Dinocampus coccinellæ*, *Ann Ent Soc Am*, **19**. 465–498
CHAPMAN, J W, and R W GLASER, 1916 Further studies on wilt of gypsy-moth caterpillars, *Jour Econ Ent*, **9**· 149–163
CLAUSEN, C P, *et al* 1927. Parasites of *Popillia japonica* in Japan and Chosen and their introduction into the United States, *U S Dept Agr, Bull* 1429
COLLINS, C W, and C E HOOD, 1920 Life history of *Eubiomyia calosoma*, a tachinid parasite of calosoma beetles, *Jour Agr Res*, **18** 483–498
CRIDDLE, N, 1924 Two problems in natural control, *Ont Ent Soc, Ann Rept* **54**: 16–18
CROSSMAN, S S, 1922. *Apanteles melanoscelus*, an imported parasite of the gypsy moth, *U S Dept Agr, Bull* 1028
CULVER, J J, 1919 A study of *Compsilura concinnata* an imported tachinid parasite, *U S Dept Agr, Bull* 766
FISKE, W F, 1903 A study of the parasites of the American tent-caterpillars, *N. H. State Coll Agr Exp Sta, Tech Bull* 6

GLASER, R. W, 1918 A new bacterial disease of gypsy-moth caterpillars, *Jour Agr Res* **13**: 515–532
———, 1925 Specificity of bacterial diseases, *Jour Econ. Ent*, **18**: 769–771
———, 1927 Studies of polyhedral diseases of insects, *Ann Ent Soc Am*, **20**: 319–342
GRAHAM, S A, 1918 An interesting habit of a wax-moth parasite, *Ann Ent Soc Am*. **11**. 175–180
HEWITT, C G., 1912 The large larch sawfly, *Can Dept Agr. Div Ent*, *Bull* 10.
HOWARD, L O, 1897 A study in insect parasitism, *U. S Dept Agr. Div Ent*, *Bull* 5
MUESEBECK, C F. W and S M. DOHANIAN, 1927 A study in hyperparasitism, *U S Dept Agr*, *Bull* 1487
PEMBERTON, C E, and H. F WILLARD, 1918 A contribution to the biology of fruit-fly parasites in Hawaii *Jour Agr Res* **15**: 419–466
SHELFORD, V E, 1926 The relation of parasites to weather conditions, *Jour Econ Ent*, **19**: 283–289
SPEARE, A J, 1920 Further studies of *Sorosporella uvella*, *Jour Agr Res*, **18**: 399–440
WEBBER, R T and J V SCHAFFNER, 1926 Host relations of *Compsilura concinnata* Meigen, *U S, Dept Agr*, *Bull* 1363
WHITE, G F, 1924 Cutworm septicemia, *Jour Agr Res*, **26**· 487–495

Chapter XVII—Predators

BURGESS, A F and C W COLLINS, 1917 The genus Calosoma, *U S Dept Agr*, *Bull* 417
DUSTAN, A G, 1923 The natural control of the white-marked tussock-moth, *Proc Acadian Ent*, *Soc*, **8**· 109–126
FELT, E P, 1906 *New York State Museum*, Mem **8**:
FORBES, S A, 1882 The regulative action of birds upon insects oscillations, *Ill State Lab Nat Hist*, *Bull* 6.
HOPKINS, A D, 1899 Preliminary report on insect enemies of forests in the Northwest, *U S Dept Agr Div Ent Bull* **21**· 13–15
MCATEE, W L, 1925 The role of vertebrates in the control of insect pests, *Smithsonian Inst Rept*, pp 415–437
———, 1926 The relation of birds to woodlots in New York State, *Roosevelt Wild Life Forest Exp Sta*, **4**: 1–154
QUAYLE, H J, 1911 The black scale, *Cal Agr Exp Sta*, *Bull* 223
ROSS, W A, 1918 Some ladybird beetles destructive to plant lice, *Agr Gazette Can*, **5** 344–347
SMITH, H S, 1922 Report of the bureau of pest control, *Cal Dept Agr*, *Bull* **11**· 793–838
SMITH, R C, 1922 The biology of the Chrysopidæ, *Cornell Agr Exp Sta*, *Memoir* **58**
TOTHILL, J D 1919 Some notes on the natural control of the oyster-shell scale, *Bull Ent*, *Res*, **9**· 183–196
———, 1922 The natural control of the fall webworm, *Can. Dept Agr*, *Tech Bull* **3** 2–107

INDEX